U.S. DEPARTMENT OF COMMERCE
National Technical Information Service
PB-248 110

INITIAL SCIENTIFIC AND MINIECONOMIC REVIEW OF MONURON.

SUBSTITUTE CHEMICAL PROGRAM

MIDWEST RESEARCH INSTITUTE

PREPARED FOR
ENVIRONMENTAL PROTECTION AGENCY

NOVEMBER 1975

KEEP UP TO DATE

Between the time you ordered this report—which is only one of the hundreds of thousands in the NTIS information collection available to you—and the time you are reading this message, several *new* reports relevant to your interests probably have entered the collection.

Subscribe to the **Weekly Government Abstracts** series that will bring you summaries of new reports *as soon as they are received by NTIS* from the originators of the research. The WGA's are an NTIS weekly newsletter service covering the most recent research findings in 25 areas of industrial, technological, and sociological interest—invaluable information for executives and professionals who must keep up to date.

The executive and professional information service provided by NTIS in the **Weekly Government Abstracts** newsletters will give you thorough and comprehensive coverage of government-conducted or sponsored research activities. And you'll get this important information within two weeks of the time it's released by originating agencies.

WGA newsletters are computer produced and electronically photocomposed to slash the time gap between the release of a report and its availability. You can learn about technical innovations immediately—and use them in the most meaningful and productive ways possible for your organization. Please request NTIS-PR-205/PCW for more information.

The weekly newsletter series will keep you current. But *learn what you have missed in the past* by ordering a computer **NTISearch** of all the research reports in your area of interest, dating as far back as 1964, if you wish. Please request NTIS-PR-186/PCN for more information.

WRITE: Managing Editor
5285 Port Royal Road
Springfield, VA 22161

Keep Up To Date With SRIM

SRIM (Selected Research in Microfiche) provides you with regular, automatic distribution of the complete texts of NTIS research reports *only* in the subject areas you select. SRIM covers almost all Government research reports by subject area and/or the originating Federal or local government agency. You may subscribe by any category or subcategory of our WGA **(Weekly Government Abstracts)** or **Government Reports Announcements and Index** categories, or to the reports issued by a particular agency such as the Department of Defense, Federal Energy Administration, or Environmental Protection Agency. Other options that will give you greater selectivity are available on request.

The cost of SRIM service is only 45¢ domestic (60¢ foreign) for each complete microfiched report. Your SRIM service begins as soon as your order is received and processed and you will receive biweekly shipments thereafter. If you wish, your service will be backdated to furnish you microfiche of reports issued earlier.

Because of contractual arrangements with several Special Technology Groups, not all NTIS reports are distributed in the SRIM program. You will receive a notice in your microfiche shipments identifying the exceptionally priced reports not available through SRIM.

A deposit account with NTIS is required before this service can be initiated. If you have specific questions concerning this service, please call (703) 451-1558, or write NTIS, attention SRIM Product Manager.

This information product distributed by

NTIS U.S. DEPARTMENT OF COMMERCE
National Technical Information Service
5285 Port Royal Road
Springfield, Virginia 22161

PB 248 110

SUBSTITUTE CHEMICAL PROGRAM

INITIAL SCIENTIFIC AND MINIECONOMIC REVIEW OF MONURON

NOVEMBER 1975

U.S. ENVIRONMENTAL PROTECTION AGENCY
OFFICE OF PESTICIDE PROGRAMS
CRITERIA AND EVALUATION DIVISION
WASHINGTON, D.C. 20460

EPA 540/1-75-028

Reproduced by
NATIONAL TECHNICAL
INFORMATION SERVICE
US Department of Commerce
Springfield, VA. 22151

For sale by
National Technical Information Service
Springfield, Va. 22151

Limited copies are available from
EPA Form and Publication Center
M-D-41
Research Triangle Park, N.C. 27711

BIBLIOGRAPHIC DATA SHEET

1. Report No. EPA-540/1-75-028

2\.

3. Recipient's Accession No. PB248110

4. Title and Subtitle
Initial Scientific and Minieconomic Review of Monuron
Substitute Chemical Program

5. Report Date November 1975

6\.

7. Author(s)

8. Performing Organization Rept. No.

9. Performing Organization Name and Address
Midwest Research Institute, Kansas City, Missouri
·Thomas L. Ferguson

10. Project/Task/Work Unit No.

11. Contract/Grant No.
#68-01-2448

12. Sponsoring Organization Name and Address
EPA, Office of Pesticide Programs, Criteria and Evaluation
Division, Washington, D.C. 20460

13. Type of Report & Period Covered

14\.

15. Supplementary Notes

16. Abstracts

This is the 8th in a series of in-depth scientific literature searches which review the safety and efficacy of substitute chemicals registered by EPA as possible replacements for cancelled or suspended pesticides or pesticides in litigation. The reviews are part of the Substitute Chemical Program, initiated under PL 93-135 (Oct. '73). This report on Monuron, a registered substitute herbicide for certain cancelled and suspended uses of 2,4,5-T, covers all uses of Monuron and is intended to be adaptable to future needs. The data contained in this report was not intended to be complete in all areas. Data searches ended in April, 1975. The review was coordinated by a team of EPA scientists in the Criteria and Evaluation Division of the Office of Pesticide Programs. Draft copies of the report have been reviewed by the scientific staffs of EPA's National Environmental Research Centers and their associated laboratories. E.I.du Pont de Nemours and Co., a manufacturer of monuron, reviewed the draft of this report and made certain comments and additions.

17. Key Words and Document Analysis. 17a. Descriptors

Monuron
2,4,5-T
herbicide
Alternative Chemicals Program
Public Law 93-135
photodecomposition products of Monuron
Goats
Rats-- hepatic microsomal enzyme activity

tumorigenicity to rats and dogs
fish toxicity
quail, pheasant , and mallard ducks
noncrop uses
80% wettable powder
Use in California -- major crops
Monuron - TCA
Economic benefits

efficacy
production and use
food tolerances
acceptable intake
environmental effects

17b. Identifiers/Open-Ended Terms

PRICES SUBJECT TO CHANGE

17c. COSATI Field/Group

18. Availability Statement

19. Security Class (This Report) UNCLASSIFIED

20. Security Class (This Page) UNCLASSIFIED

21. No. of Pages 120

22. Price 550

SUBSTITUTE CHEMICAL PROGRAM

INITIAL SCIENTIFIC
AND
MINIECONOMIC REVIEW
OF
MONURON

NOVEMBER 1975

U.S. ENVIRONMENTAL PROTECTION AGENCY
OFFICE OF PESTICIDE PROGRAMS
CRITERIA AND EVALUATION DIVISION
WASHINGTON, D.C. 20460

EPA-540/1-75-028

1a

This report has been compiled by the Criteria and Evaluation Division, Office of Pesticide Programs, EPA, in conjunction with other sources listed in the Preface. Mention of trade names or commercial products does not constitute endorsement or recommendation for use.

PREFACE

The Alternative (Substitute) Chemicals Program was initiated under Public Law 93-135 of October 24, 1973, to "provide research and testing of substitute chemicals." The legislative intent is to prevent using substitutes, which in essence are more deleterious to man and his environment, than a "problem" pesticide suspected of causing "unreasonable adverse effects to man or his environment." The major objective of the program is to determine the suitability of potential substitute chemicals which now or in the future may act as replacements for those uses (major and minor) of pesticides that have been cancelled, suspended, or are in litigation or under internal review for potential unreasonable adverse effects on man and his environment.

The substitute chemical is reviewed for suitability considering all applicable scientific factors such as: chemistry, toxicology, pharmacology and environmental fate and movement; and socio-economic factors such as: use patterns and costs and benefits. EPA recognizes the fact that even though a compound is registered, it still may not be a practical substitute for a particular use or uses of a problem pesticide. The utilitarian value of the "substitute" must be evaluated by reviewing its biological and economic data. The reviews of substitute chemicals are carried out in two phases. Phase I conducts these reviews based on data bases readily accessible at the present time. An Initial Scientific Review and Minieconomic Review are conducted simultaneously to determine if there is enough data to make a judgment with respect to the "safety and efficacy" of the substitute chemical. Phase II is only performed if the Phase I reviews identify certain questions of safety or lack of benefits. The Phase II reviews conduct in-depth studies of these questions of safety and cost/benefits and consider both present and projected future uses of the substitute chemicals.

The report summarizes rather than interprets scientific data reviewed during the course of the studies. Data is not correlated from different sources. Opinions are not given on contradictory findings. Where applicable, the review also identifies areas where technical data may be lacking so that appropriate studies may be initiated to develop desirable information.

This report contains the Phase I Initial Scientific and Minieconomic Review of Monuron. Monuron was identified as a registered substitute chemical for certain cancelled and suspended uses of 2,4,5-T.

The review covers all uses of monuron and is intended to be adaptable to future needs. Should monuron be identified as a substitute for a problem pesticide other than 2,4,5-T, the review can be updated and made readily available for use. The data contained in this report was not intended to be complete in all areas. Data-searches ended in April, 1975. The review was coordinated by a team of EPA scientists in the Criteria and Evaluation

Division of the Office of Pesticide Programs. The responsibility of the team leader was to provide guidance and direction and technically review information retrieved during the course of the study. The following EPA scientists were members of the review team: Eugene Pelletier, Ph.D. (Team Leader); Hudson Boyd (Chemistry); Stewart Colten (Chemistry); Padma Datta, Ph.D. (Chemistry); Elsie Kelley (Pharmacology and Toxicology); John Leitzke (Fate and Significance in the Environment); Darrel Gwinn, Ph.D. (Fate and Significance in the Environment); Richard Petrie (Registered Uses); Jeff Conopask, Ph.D. (Economics).

Data research, abstracting, and collection were primarily performed by Midwest Research Institute (MRI), Kansas City, Missouri (EPA Contract #68-01-2448) under the direction of Mr. Thomas L. Ferguson. RvR Consultants, Shawnee Mission, Kansas, under a subcontract to MRI, assisted in data collection. The following MRI scientists were principal contributors to report: James V. Dilley, Ph.D., David F. Hahlen, Thomas L. Ferguson, Alfred F. Meiners, Ph.D., William J. Spangler, Ph.D., Frank E. Wells, Ph.D. Rosmarie von Rumker, Ph.D. (RvR Consultants) also contributed to the report.

Draft copies of the report have been reviewed by the scientific staffs of EPA's National Environmental Research Centers and their associated laboratories. Comments and supplemental material provided by the following laboratories are greatly appreciated and have been incorporated into this report: Gulf Breeze Environmental Research Laboratory, Gulf, Gulf Breeze, Florida and National Ecological Research Laboratory, Corvallis, Oregon. E. I. du Pont de Nemours and Company, Inc., a manufacturer of monuron, reviewed the draft of this report and made certain comments and additions.

GENERAL CONTENTS

Page

List of Figures vi

List of Tables vii

Part I. Summary 1

Part II. Initial Scientific Review 11

- Subpart A. Chemistry 11
- Subpart B. Pharmacology and Toxicology 35
- Subpart C. Fate and Significance in the Environment 51
- Subpart D. Production and Use 91

Part III. Minieconomic Review 107

FIGURES

No. Page

1 Proposed Photodecomposition Reaction Sequence of Monuron in Aqueous Solution under Aerobic Conditions 26

2 Photolysis of Monuron in Methanol under Anaerobic Conditions 28

3 Photolysis of Fenuron in Methanol under Anaerobic Conditions 29

TABLES

No. Page

1 Photodecomposition Products of Monuron 25

2 Acute Toxicity of Monuron to Goats by Single Drench 40

3 Induction of Heptatic Microsomal Enzyme Activity of Rats 42

4 Summary of the Action of Monuron on Experimental Animals 44

5 Results of the Action of Monuron on Experimental Animals 45

6 Observations on the Tumorigenicity of Monuron to Rats and Dogs . . 46

7 Acute Toxicity of Monuron to Fish 53

8 Effect of Formulation on the Acute Toxicity of Monuron to Fish . . 54

9 Effects of Monuron on Quail, Pheasant and Mallard Ducks 60

10 Effect of Monuron on Bobwhite Quail and Pheasant 60

11 Monuron Noncrop Uses 93

12 Monuron 80% Wettable Powder Specimen Label 94

13 Estimated Uses of Monuron in the U.S. by Use Categories, 1973 . . 101

14 Monuron Uses in California by Major Crops and Other Uses, 1970 to 1973 102

15 Use of Monuron (including Monuron-TCA) in California in 1972 by Crops and Other Uses, Applications, Quantities, and Acres Treated 104

16 Use of Monuron (including Monuron-TCA) in California in 1973 by Crops and Other Uses, Applications, Quantities, and Acres Treated 105

17 Economic Benefits of Chemical and Alternative Control 112

PART I.   SUMMARY

CONTENTS

Page

Production and Use 2

Toxicity and Physiological Effects 3

Food Tolerances and Acceptable Intake 5

Environmental Effects 5

Efficacy and Cost Effectiveness 9

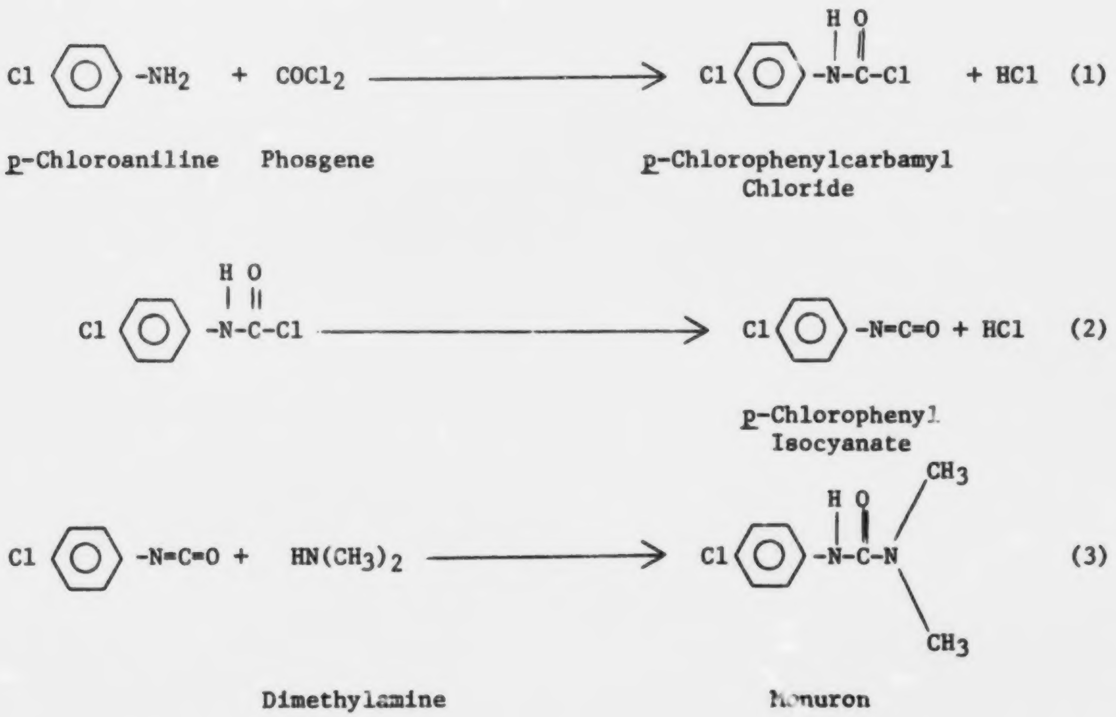
This section contains a summary of the "Initial Scientific and Mini-economic Review" conducted on monuron. The section summarizes rather than interprets scientific data reviewed.

Production and Use

Monuron [(3-p-chlorophenyl)-1, 1-dimethylurea] is a broad-spectrum herbicide used for the control of many grasses and herbaceous weeds on noncropland areas, such as rights-of-way, industrial sites, and drainage ditchbanks.

The chemical, the first of a series of urea herbicides, was discovered by researchers of the E. I. du Pont de Nemours and Company, Inc. (du Pont) in 1951. The specific properties of water solubility and resistance to microbial decomposition were designed through manipulation of molecular substitutions. Varying degrees of soil stability and water solubility were achieved through the amount of chlorination and the choice of alkyl groups. The compound was first registered for use in 1955. The only domestic producer is du Pont.

Eight methods have been reported for the synthesis of monuron. One is:


Cl
-NH2
+ COCl2
H O
-N-C-Cl
+ HCl
(1)
p-Chloroaniline
Phosgene
p-Chlorophenylcarbamyl Chloride
-N=C=O + HCl
(2)
p-Chlorophenyl Isocyanate
-N=C=O +
HN(CH3)2
CH3
-N-C-N
(3)
Dimethylamine
Monuron

Du Pont also holds a patent for an alternate method of producing p-chlorophenylcarbamyl chloride from phenyl isocyanate which may be used instead of the reaction, as cited in Equation 1.

Monuron is a white, odorless, crystalline solid with very low solubility in hydrocarbon solvents or water. Monuron has a low vapor pressure, and is noncorrosive and nonflammable. It can be decomposed either by ultraviolet radiation or certain microorganisms. It is fairly stable to oxidation and hydrolysis under normal conditions.

The most widely used formulation of monuron is an 80% wettable powder. Monuron is also available in several granular formulations, both as the only active ingredient, and in combination with sodium metaborate, sodium tetraborate, trichloroacetic acid, and sodium chlorate.

The domestic supply of monuron in 1973 is estimated to have ranged from 550,000 to 950,000 lb, including approximately 150,000 lb of imports. About one-sixth of the domestic supply was used for agricultural purposes, and one-sixth by government agencies, with essentially the remainder being used by the industrial/commercial sector.

Toxicity and Physiological Effects

Data was found on the toxicity of monuron to laboratory and domestic animals. An acute oral LD_{50} for monuron in the range of 3.4 to 3.6 g/kg body weight was reported for male albino rats. The reported value for a monuron formulation, NH-174 (8% monuron, 86% sodium tetraborate) for groups of mixed male and female rats was 5.6 (±0.25) g/kg body weight. In one study, the approximate lethal oral dose was 7.5 g/kg. The only acute oral LD_{50} value reported in available studies was 1.48 (±0.21) g/kg body weight for male albino rats.

Only approximate lethal oral doses have been reported for other laboratory animals; the respective values for guinea pigs and rabbits were 670 and 1,500 mg/kg body weight.

General signs of toxicity to rats are those of methemoglobinemia, such as cyanosis, enlarged dark spleen, and compensatory red blood cell (RBC) formation in the spleen and bone marrow. Dead animals generally show pulmonary edema, congestion, and hemorrhaging accompanied by anemia of liver, kidneys, and spleen.

Administration of 5 subacute doses per week (500 mg/kg by stomach tube) for 2 weeks to rats resulted in cyanosis and continued weight losses, but no deaths. Continuous (6 weeks) administration in ground laboratory chow at levels of 0.005%, 0.05% and 0.5% resulted in clinical signs of intoxication only at the highest dose. At necropsy, animals fed 0.5% monuron showed signs of methemoglobinemia and possible blood cell degeneration.

Monuron fed to rats at levels up to 2,500 ppm (in the feed) caused no deaths over a 2-yr period, although decreased weight (compared to controls) was seen at the highest dose level. The weight differential was more pronounced in males than in females. Histological examination revealed no tissue abnormalities other than slightly increased liver and spleen weights at the 2,500 ppm level. The no-effect level was 250 ppm.

One-year chronic feeding studies of beagles caused no deaths, no abnormal animal health effects, and no abnormalities in histological profiles at the highest daily dose fed (25.0 mg/kg body weight). The no-effect level was 1,000 ppm.

Studies with domestic animals indicated an acute oral toxicity for goats in the range of 600 to 1,600 mg/kg.

Sheep survived 10 daily doses of monuron at 50 mg/kg by drench. Four doses at 100 mg/kg resulted in signs of toxicity and weight loss, with death occurring after 9 doses.

Cattle survived multiple daily doses of 25 to 250 mg/kg of monuron, 80% wettable powder (WP) by drench. Diarrhea developed, without weight loss, at doses of 50 to 250 mg/kg. At a single dose of 500 mg/kg, a yearling exhibited signs of poisoning with an 11% weight loss, but survived.

In chickens, 25 and 50 mg/kg dosages resulted in 14 and 27% reduction in weight gain, respectively. A 20% mortality resulted from administration of 100 mg/kg, while 250 mg/kg resulted in 100% mortality after 6 to 9 doses.

A dose of 2,250 mg/kg applied to the unabraded skin of a rabbit caused no irritation or clinical signs of toxicity. Aqueous pastes (4, 8, 16, and 23 g/kg) applied over 10% of the body surface of rabbits for a 24-hr period resulted in no apparent toxicity.

Tests with guinea pigs indicated no skin irritation and no skin sensitization.

Application of saturated solution to the eyes of rabbits indicated no irritation of ocular tissue.

Rats exposed to fine dusts (5 to 35 μm) at a concentration equal to 245.5 g/m^3 of monuron for 4 hr exhibited no clinical signs of toxicity over a 14-day postobservation period.

Definitive studies on the absorption, distribution, and residual potential of monuron have not been conducted with mammalian systems. Studies have been made on the metabolic fate in rats by urinalysis of rats fed 4.8 g of monuron over an 8-day period. The major metabilites retained the urea structure and the chief pathway of degradation appeared to be a stepwise demethylation with a minor step leading to hydroxylation of the benzene nucleus. About 15% of the administered compound was excreted as N-(4-chlorophenyl) urea, 7% as

N-(2-hydroxy-4-chlorophenyl) urea, and about 2.5% as N-(3-hydroxy-4-chlorophenyl) urea. The transformations of monuron in plants and animals, and by soil bacteria appear to be similar.

The enzyme systems for monuron degradation in mammalian liver appear to be inducible rather than constitutive.

A 3-generation reproductive study with dosages up to 2,500 ppm monuron in the feed of rats indicated no deviation from normal reproduction, no effect on lactation, and no clinical signs of toxicity. At the 2,500 ppm dosage, a slight reduction in average number of pups in each of 6 litters was noted.

In teratogenic tests, monuron caused no significant increase in anomalies in 3 strains of mice at 215 mg/kg.

Results of experiments on the oncogenicity of monuron are variable. In a preliminary screening study with mice and rats, a significantly higher tumor rate was reported after an 18-month feeding period for rats (450 mg/kg in ration), and after a 15-week feeding period (6 mg/week as single dose) for mice. The results of a more detailed evaluation in mice were indecisive, with the treated mice having a slightly higher, but not statistically significant, tumor incidence.

Still other chronic feeding studies with dogs and rats indicated no significant increase in tumors that could be attributed to monuron over feeding periods of 1 and 2 yr, respectively.

Monuron did not induce point mutations when evaluated with histidine dependent mutants of Salmonella typhimurium.

Food Tolerances and Acceptable Intake

In the past, monuron was registered for selective control of weeds on several crops. Tolerances for monuron residues were established at 7 ppm for asparagus, and 1 ppm on avocados, cottonseed, grapes, dry bulb onions, pineapples, spinach, sugarcane, and several citrus fruits. However, due to inadequate data to support the safety of tolerances, all tolerances for monuron in food and feedstuffs were revoked, effective July 26, 1973. Monuron is no longer registered for use on any agricultural crop.

An acceptable daily intake (ADI) has not been determined for monuron.

Environmental Effects

The acute toxicity data for fish from laboratory investigation is summarized as follows:

Species	Exposure time (hr)	Toxicity calculation	Toxicity measure (ppm)
Striped mullet (Mugil cephalus)	48	LC_{50}	16.3
White mullet (Mugil curema)	24	TL_m	20.0
	48	TL_m	16.3
Coho salmon (Oncorhynchus kisutch)	24	TL_m	115
	48	TL_m	110
Rainbow trout (Salmo gairdneri)	24	LC_{50}	180
	48	LC_{50}	100
Carp (Cyprinus carpio)	48	TL_m	>10
Largemouth bass (Micropterus salmoides)	48	10% Mortality	230

Goldfish (Carassius auratus) have been reported to survive a 5-day exposure to 59.5 ppm monuron, and a 35-day exposure to 14.9 ppm monuron. Twenty ppm did not cause death of small bluegills (Lepomis macrochirus) during a 12-day exposure period, nor did exposure to 10 ppm monuron for 8 days cause any loss of fry of bluegill or lake chubsucker (Erimyzon sucetta). However, green sunfish (Lepomis cyanellus) fry survived no longer than 5 days, and smallmouth bass (Micropterus dolomieu) fry survived for only 4 days when exposed to 10 ppm monuron.

A Russian formulation of 10% monuron and 10% TCA (TCA alone is more toxic to fish than monuron alone) applied at a rate of 40 kg/ha AI (20 mg/l AI) to artificial ponds caused decreased hemoglobin, erythrocyte and hematocrit counts in Leuciscus idus and Rutilus rutilus for up to 75 days after treatment. There was also a 46% loss of fish over the test period.

Exposure of adult white shrimp (Penaeus setiferus) to 1.0 mg/l concentrations of monuron for 24 hr had no effect; exposure of the Eastern oyster (Crassostrea virginica) to 2.0 mg/l for 96 hr caused a 12% decrease in shell growth. The 50% immobilization concentration (IC_{50}) of monuron to Daphnia magna was found to be 106 ppm. Monuron at 1 to 2 ppm reduced the number and weight of bottom-dwelling, fish-food organisms (primarily weed-clinging species of Gastropoda, Odonata and Trichoptera) by 38 and 18%, respectively.

The growth of pure cultures of marine plankton (Protococcus species, Chlorella species, and Dunaliella euchlora) was completely inhibited at 0.02 ppm monuron; 0.25 and 0.28 ppm completely inhibited growth of unicellular algae (Chlorococcum species, Dunaliella tertiolecta, and Phaeodactylum tricornutum at 0.28 ppm, and Isochrysis galbana at 0.28 ppm). Monuron has also been shown to be effective in controlling a number of other algae at 0.5 to 2.0 mg/l. It has also been demonstrated that monuron is toxic to algae in the light, but not in the dark, regardless of presence of an energy source.

The oral LC_{50} of monuron for bobwhite quail (Colinus virginianus), Japanese quail (Coturnix coturnix japonica), and the mallard duck (Anas *platyrhynchos*) is greater than 5,000 ppm in the feed; the LC_{50} for the ring-necked pheasant (*Phasianus colchicus*) is 4,682 ppm.

The LD_{50} of monuron to honeybees (*Apis mellifera*) is 110 µg/bee when applied as dust. Probit analysis of test data indicates that high increases in dosage rate would be required to increase toxicity to bees.

The interactions of monuron with lower terrestrial organisms have been fairly extensively investigated. The major results from studies of various microflora and microfauna are summarized as follows:

Species	Test rate or conditions	Result
Microflora		
Aspergillus niger	1,000 ppm	Complete inhibition
Fungus of the genus *Fusarium*	Agar	Apparent utilization of monuron as carbon source
Rhizopus japonicus	Aerobic conditions at 30° C	Demethylation of monuron
Bacillus sphaericus	Soil	Decomposition of monuron
Pseudomonas fluroescens	5 to 40 mg/l	Stimulation of dehydrogenase in absence of other energy source
Yeast mitochondria	-	Inhibition of respiration
Soil microorganisms (including *Pseudomonas*, *Bacillus*, *Penicillium* and *Aspergillus*)	250 ppm in agar	No adverse effect on population
Soil organisms	0.9 to 2.7 lb/acre	No effect on nitrogen or water-soluble organic content of soil
Soil organisms	1.3 lb/acre	Decreased number of *Azotobacter* and ammonia-fixing bacteria
Soil organisms	7.1 lb/acre	Decrease in total quantity microorganisms; increase in actinomycetes, and nitrogen-fixing organisms
Soil organisms	Normal field rates	No effect on oxygen uptake
Microfauna		
Soil invertebrates	10 lb/acre	Significantly fewer wireworms (Elateridae), millipedes (Diplopoda), earthworms (Lumbricidae), spring tails (Collembola), and mites

Species	Test rate or conditions	Result
		(Acarinal) (virtual elimination of grasses, increased wild carrot and sheep sorrel)
Soil invertebrates	17.8 lb/acre	Decreased number of millipedes and spring tails
Earthworms	Emersion in solution for 2 hr	10% mortality at 1 ppm; 100% mortality at 100 ppm

Reports on the effect of monuron on soil nitrification are in conflict. Applications of monuron at 1 to 5 lb/acre were reported to inhibit soil nitrification. However, application rates of 7.1 to 8.9 lb/acre and 50 ppm were reported to have no noticeable effect on soil nitrification rate and nitrifying microorganisms, respectively. From still another investigation (involving growth and metabolism studies of Azotobacter and Clostridium species), it was concluded the phenylurea herbicides are without effect on free-living, nitrogen-fixing organisms except at concentrations far in excess of normal agricultural field rates.

The persistence of monuron in the soil has been extensively investigated both in the United States and abroad. These studies have, in general, shown that when monuron is applied at the lower, selective rates (which are no longer registered in the United States) phytotoxic concentrations disappear within 1 yr. For example, one study involving several selective application rates and soil types had an overall rate of monuron disappearance of 83% after 12 months. In a recent review of herbicides, it was concluded that 80% of the monuron applied at selective rates would disappear within 1 yr of application for most climatic and edaphic conditions. When monuron is applied at nonselective rates for total vegetation control (current registered uses), phytotoxic activity can persist for several seasons. Massive rates of monuron (20 to 200 lb/acre) have required up to 3 yr to dissipate.

The mobility of monuron (and several other herbicides) in soil have been evaluated by measuring its R_f value on a thin-layer (400 μm) soil chromatogram for 4 agricultural soils. In each of these soils, monuron was intermediate in its mobility compared to other similarly tested herbicides. The mobility of monuron is apparently not affected by pH over the range of 5.4 to 8.9 although mobility is apparently reduced with increased content of organic matter in the soil.

Greenhouse leaching studies (72 in of simulated rainfall over a 90-day test) showed that 4 to 62% of the original monuron remained in the soil, 0 to 56% was found in the leachate, with unaccounted losses of 38 to 85%. The investigators concluded that leaching can occur under conditions of extremely high rainfall on porous soils. Russian investigators have also shown that monuron was rapidly backed down into "red-earth soil" under intensive rainfall.

Data on the monuron content of water is limited. One investigation of the persistence of monuron in river water has been reported. Acetone solutions of monuron were injected into water samples which were maintained at room temperature and exposed to natural and artificial light. The percent of monuron remaining in the test samples was as follows:

Quantity remaining (%)	Time (weeks)
40	1
30	2
20	4
None detected	8

Photodecomposition of aqueous monuron solutions has been investigated. Fourteen days exposure to summer sunlight in California yielded decomposition of less than 6%. Photodecomposition is enhanced, however, in the presence of naturally-occurring photosensitizers such as riboflavin-5-phosphate.

Data is not available on the origin, presence, or persistence of monuron in the air. The low vapor pressure of monuron and its use pattern indicates that little monuron will be present in the air.

In bioaccumulation and biomagnification studies, a Russian formulation of 10% monuron and 10% trichloroacetic acid (TCA) was applied to artificial ponds stocked with fish at a rate of 40 kg/ha (20 kg/ha of monuron). Over the 60-day test period the concentration of monuron in the water ranged from 0.1 to 0.3 mg/l. After 5 days monuron concentrations of 15 ppm were found in Rutilus rutilus heart tissue and 5.3 ppm in Leuciscus cephalus brain tissue. In Leuciscus idus muscle tissue, monuron concentrations decreased from 0.95 ppm after 10 days to trace amounts after 60 days.

Efficacy and Cost Effectiveness

Monuron is a preemergent herbicide used for control of annual weeds and grasses along canal banks, railroads, highways and utility lines. Until 1973, it had been registered for use in controlling numerous grasses and weeds in selected commercial crops.

Monuron is used at rates varying from 20 to 100 lb/acre for control of a wide variety of annual weeds and grasses along highways, railroads, levees, irrigation ditches and other specific locations. Several tests have shown that rates of 40 to 100 lb/acre provide 80 to 100% seasonal control of a broad variety of weeds and grasses. A test to determine the long-term effect of monuron has shown that massive doses of 224 lb/acre have resulted in 80 to 100% control of most weeds and grasses in 1 yr, but by the end of the second yr, 47% of the area was again covered with vegetation. Coverage increased to 80% at the end of the third yr and 100% at the end of 15 yr.

Tests on specific grasses have shown that monuron at 80 lb/acre will kill 80 to 90% of nutgrass tubers. Monuron at 40 lb/acre controlled bindweed for 2-1/2 months; at 1.0 lb/acre it controlled 81% of clubmoss.

Comparisons of the costs of soil-applied herbicides to those of alternative methods (such as mechanical or hand-labor control of non crop weeds and grasses) for control of weed and brush along California irrigation ditches showed economic effects ranging from an increased cost of $34.70/acre for chemical control, as compared to mechanical methods, and a $118.10 cost reduction for chemical control when compared to hand weeding.

PART II. INITIAL SCIENTIFIC REVIEW

SUBPART A. CHEMISTRY

CONTENTS

Page

Synthesis and Production Technology 12

Physical Properties 17

Analytical Methods 19

  Multi-Residue Methods 19
  Residue Analysis. 19
  Formulation Analysis. 21

Composition and Formulation 21

Chemical Properties, Degradation and Decomposition Processes 21

    Photodecomposition. 23
    Other Properties and Reactions. 27

Occurrence of Residues in Food and Feed Commodities 30

Acceptable Daily Intake 30

Tolerances. 30

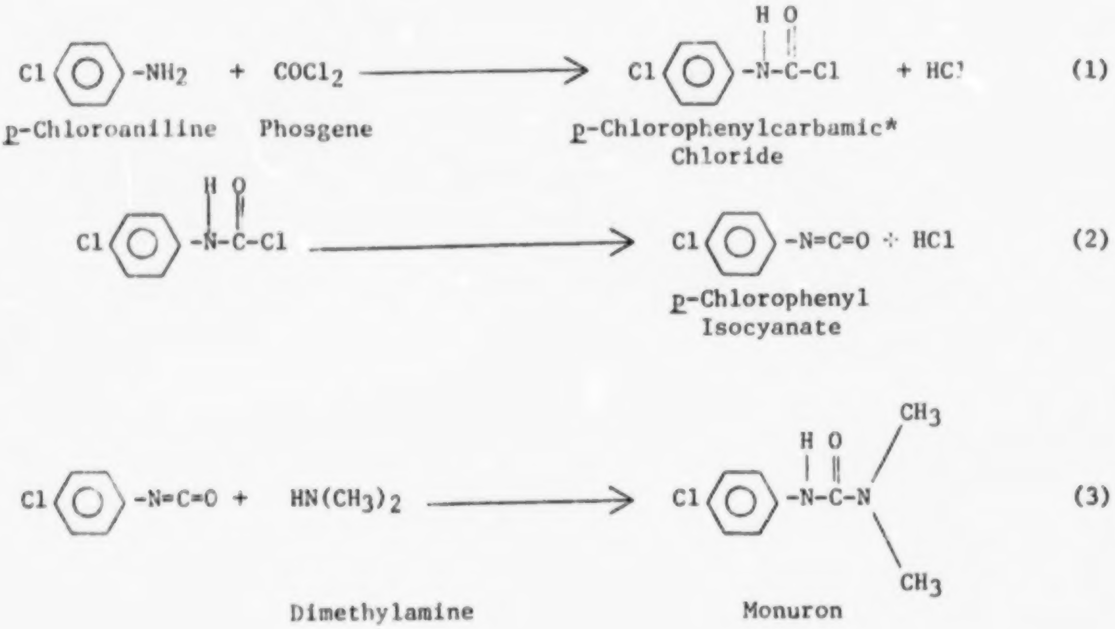
References. 31

Synthesis and Production Technology

Monuron [(3-(p-chlorophenyl)-1, 1-dimethylurea], the first of a series of phenyl urea herbicides, was discovered by du Pont researchers in 1951. It was the first of a group selected by du Pont in which the specific properties of water solubility and resistance to microbial decomposition were designed through manipulation of molecular substitutions. Varying degrees of soil stability and water solubility were achieved through the amount of chlorination and the choice of alkyl groups (Martin, 1964). Monuron was first registered for use in 1955. It is presently produced domestically at a du Pont plant in La Porte, Texas (Stanford Research Institute, 1974).

Eight methods for synthesizing monuron have been reported. They are summarized below.

Method I - Sittig (1967) describes the probable method in the manufacture of monuron using p-chloroaniline, phosgene, and dimethylamine as raw materials. The reaction sequence is shown below:



Cl–C6H4–NH2 + COCl2 → Cl–C6H4–N(H)–C(=O)–Cl + HCl (1)
p-Chloroaniline
Phosgene
p-Chlorophenylcarbamic* Chloride
Cl–C6H4–N(H)–C(=O)–Cl → Cl–C6H4–N=C=O + HCl (2)
p-Chlorophenyl Isocyanate
Cl–C6H4–N=C=O + HN(CH3)2 → Cl–C6H4–N(H)–C(=O)–N(CH3)2 (3)
Dimethylamine
Monuron

---

*also called carbamyl or carbamoyl.

A partial description of the conditions for Reaction (3) is found in a patent owned by du Pont (Todd, 1953).

> The amine-isocyanate reaction is most readily carried out in the presence of an inert solvent, such as toluene, anisole, benzene, chlorobenzene, or dioxane. No catalyst is needed, and since the reaction is exothermic it is ordinarily unnecessary to supply heat. Thus, the reaction is conveniently carried out by first mixing the isocyanate with the inert solvent at room temperature and then gradually adding the secondary amine reactant while permitting the temperature to increase through the range of, say, 25 to 75°C. The trisubstituted urea products are generally quite insoluble in the solvent used and, therefore, precipitate out as formed and are readily separated from the reaction mass. The halophenyl dialkyl ureas produced are white crystalline solids. They are insoluble or only slightly soluble in water and cold benzene and, in general, appreciably soluble in dioxane, acetone, ethyl acetate, ethanol and hot benzene.

The Todd patent also describes a laboratory preparation of monuron:

> Anhydrous hydrogen chloride was passed into a solution of 191.2 parts by weight of p-chloroaniline in 1,550 parts by weight of dioxane until in excess. The reaction temperature was permitted to rise to 70 - 75°C during the addition, and after the solution was saturated, phosgene was passed into the slurry at the same temperature until a clear solution of p-chlorophenyl isocyanate was obtained (about 4 hr). The excess phosgene and hydrogen chloride were removed by distillation of approximately 300 parts by weight of the dioxane. After cooling to 25°C, dimethylamine was passed into the reaction mixture at 25-40° until present in excess. The slurry was cooled to 10° and 3-(p-chlorophenyl)-2, 2-dimethylurea (261.5 parts by weight; 88% yield) removed by filtration.
>
> Dilution of the filtrate with water gave an additional 19.1 parts by weight of 3-(p-chlorophenyl)-1, 1-dimethylurea, increasing the total yield of crude product (M.P. 164.5 - 168°) to 280.6 parts by weight or 94.5% of theory. Recrystallation of a portion of the crude product from 95% aqueous methanol resulted in 76% recovery of shiny white scales which melted at 170.5 - 171.2°.

In another report, Sittig (1971) lists the following conditions for Reaction (3):

1. Temperature: The temperature for reaction of p-chlorophenyl isocyanate with dimethylamine is 25 to 40°C.

2. Pressure: This reaction is carried out at atmospheric pressure.

3. Reaction time: After passage of dimethylamine into the isocyanate solution until it is present in excess, the mixture may be heated an additional half hour.

4. Reaction medium: This reaction is conducted in the liquid phase.

5. Catalyst: No catalyst is employed in the condensation of dimethylamine with p-chlorophenyl isocyanate.

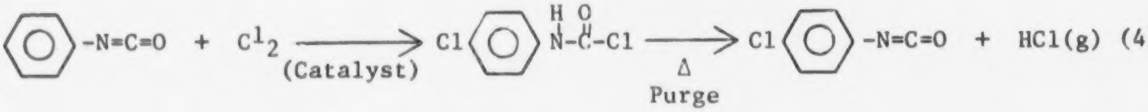
6. Reactor design: A stirred, jacketed reactor of conventional design may be used for this reaction.

7. Product recovery: The 3-(p-chlorophenyl)-1, 2-dimethylurea product precipitates from the cooled reaction mixture and is removed by filtration in a vacuum oven at 50° for over 30 min (U.S. 2,655,444).

Searle and Todd (1953) in a du Pont patent concerned with this process, explained that a molal excess of 10 to 20% of amine over isocyanate is preferred, with a reaction time of approximately 2 hr after mixing.

Method II - The sequence of Method I may be altered by treating dimethylamine with phosgene to yield dimethylcarbamyl chloride, $(CH_3)_2NCOCl$, which is then treated with p-chloroaniline (Sittig, 1967).

Method III - Du Pont also owns a patent (Julian and Siefen, 1961) for the synthesis of p-chlorophenylcarbamic chloride by chlorination of phenyl isocyanate.

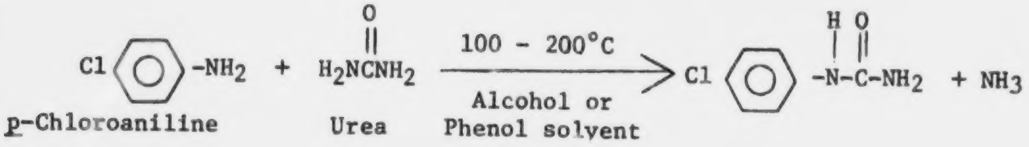


(4)

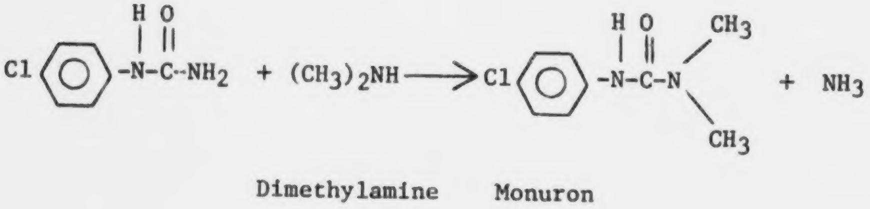
This reaction can be used as the first step of Method I.

According to this patent, the chlorination of phenyl isocyanate is carried out in two steps. In the first step, only 80 to 98% of the chlorination takes place at -15° to 15°C and at 5 atmospheric pressure. One-third or more of the feed of the first step is unchlorinated phenyl isocyanate. In the second step the remaining 2 to 20% of chlorine is added under unspecified conditions. This 2-step process avoids undesirable by-products caused by overchlorination or orthochlorination.

Method IV - A method of producing monuron that avoids the by-product hydrogen chloride is described in a patent owned by Imperial Chemical Industries (Jones, 1956). The 2 Jones method reactions are:


Cl
-NH2
+
O
H2NCNH2
100 - 200°C
Alcohol or
Phenol solvent
Cl
H O
-N-C-NH2
+ NH3
p-Chloroaniline
Urea

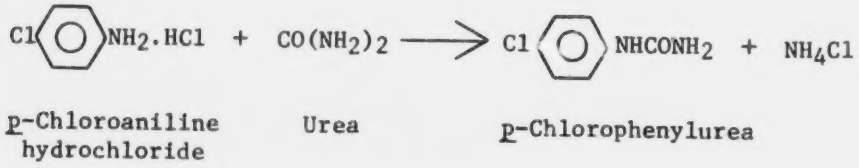
(5)


Cl
H O
-N-C-NH2
+ (CH3)2NH
Cl
H O
-N-C-N
CH3
CH3
+ NH3
Dimethylamine
Monuron

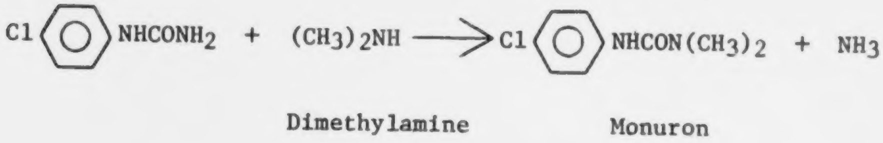
(6)

The reaction mixture is refluxed until ammonia evolution ceases, then the dimethylamine is added to the hot product until all the solvent is removed by distillation.

Method V - An alternate method of production is described in another patent issued to du Pont (Thompson 1954). The claimed advantage of the patent is that the water may be used as a solvent. The reactions for this method are:


Cl
NH2.HCl
+
CO(NH2)2
Cl
NHCONH2
+
NH4Cl
p-Chloroaniline
hydrochloride
Urea
p-Chlorophenylurea

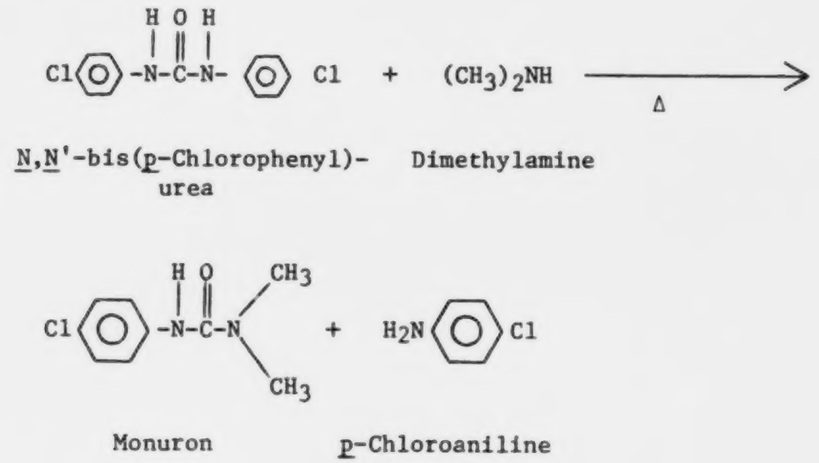
(7)


Cl
NHCONH2
+
(CH3)2NH
Cl
NHCON(CH3)2
+
NH3
Dimethylamine
Monuron

(8)

The first reaction (urea reaction) is carried out at 70° - 105° (preferably 90° - 105°) under pressure, if desired, for about 6 hr. Urea is added in 2- to 4-fold excess. The second reaction (dimethylamine reaction) is conducted under reflex at 135° - 225° for about 3.5 hr. Pressure is determined by the choice of solvent, DMF, O-dichlorobenzene, anisole, ethyl acetate, toluene or other aromatics. Excess dimethyamine is added sufficent to maintain at least .01 percent free dimethylamine in reaction mixture.

Method VI - Melnikov (1971) notes 2 methods of producing monuron in addition to methods I and II. The first additional method is:


(9)

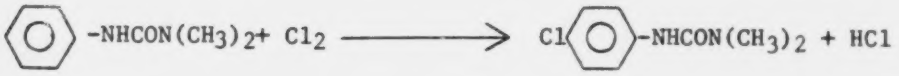
N,N'-bis(p-Chlorophenyl)-urea

Dimethylamine

Monuron

p-Chloroaniline

Method VII - The other method reported by Melnikov (1971) is direct chlorination:


(10)

Method VIII - Another method is described in a German patent owned by Quimco G.m.b.H. (Hearsey and Mehta, 1973). The first step is the preparation of an intermediate:

$$(CH_3)_2NH + CO + S \longrightarrow [(CH_3)_2H_2N] + [(CH_3)_2NCOS] \qquad (11)$$

Dimethylammonium dimethylthiolcarbamate

The solvent for this reaction may be benzene, toluene, xylene, O-dichlorobenzene, or chlorobenzene, and the reaction is carried out at 50 to 60 atmospheres and 100°C for 20 to 30 min. This intermediate is then azeotropically vacuum-distilled with the solvent and treated with p-chloroaniline to produce monuron at 95% of theoretical yield. This second reaction takes place in a chlorophenol solvent, with the p-chloroaniline present in less than stoichiometric quantity. The reactants are refluxed at 80°C or reacted at greater than 100°C under nitrogen pressure for 1 to 15 hr.

Physical Properties

Chemical names: 3-(p-chlorophenyl)-1, 1 dimethylurea
N'-(4-chlorophenyl)-N, N-dimethylurea

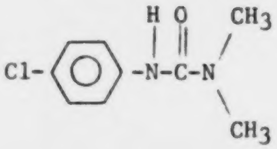
Common names: Monuron, CMU

Trade names: Telvar®

Pesticide class: Herbicide, substituted urea

Empirical formula: $C_9H_{11}ClN_2O$

Structural formula:



Molecular weight: 198.65

Analysis: C 54.41%; H 5.58%; Cl 17.85%; N 14.10%; O 8.05%.

Physical state: White, odorless, crystalline solid (Martin, 1971). Crystallization from methanol gives thin rectangular prisms. Slight odor. (Merck, 1968).

Specific gravity: 1.27 (20/20°C)

Melting point: 176 to 177°C (commercial) (Merck, 1968)
170.5 to 171.5°C (crystallized from methanol) (Merck, 1968)
174 to 175°C (Martin, 1971)

Boiling point: Decomposes at 185 to 200°C

Solubility: Zhuravlev (1969) reports the following solubilities and heats of solution of monuron in water:

Temperature (°C)	Weight % monuron	Differential heat of solution (kcal/g mole)
10	0.0195	3.41
15	0.0210	3.53
20	0.0240	3.66
25	0.0260	3.78
30	0.0290	3.91
35	0.0330	4.04
40	0.0365	4.17
45	0.0400	4.31
50	0.0440	4.44

At 25°C and pH of 5.7, the solubility is 262 ppm in water (Hurle and Freed, 1972).

Monuron is sparingly soluble in petroleum oils and polar organic solvents such as acetone (Martin, 1971). Monuron is moderately soluble in methanol, ethanol, and acetone. It is practically insoluble in hydrocarbon solvents (Merck, 1968).

The Herbicide Handbook (1970) lists the following solubilities:

Solvent	Temperature (°C)	Weight (ppm)
Acetone	27	52,000
Benzene	27	2,900
Butyl stearate	27	1,500
Cottonseed oil (refined)	27	1,100
No. 3 diesel oil	25	230
Water	25	230

Heat of solution: 3.0 kcal/mole (Hurle and Freed, 1972)

Heat of sublimation: 27.4 kcal/mole (Wiedemann, 1972)

Vapor pressure: 5×10^{-7} mm Hg at 25°C
3.4×10^{-6} mm Hg at 50°C (Hill, 1971)
Wiedemann (1972) lists the following vapor pressures for monuron, determined experimentally by thermogravimetry.

Temperature (°C)	Vapor Pressure (torr)
30.3	4.00×10^{-7}
42.8	1.83×10^{-6}
56.6	1.40×10^{-5}
57.4	1.55×10^{-5}
57.9	1.66×10^{-5}
65.6	5.29×10^{-5}
68.2	7.09×10^{-5}

Temperature (°C)	Vapor Pressure (torr)
72.5	7.91×10^{-5}
76.3	1.53×10^{-4}
83.8	3.97×10^{-4}
85.5	4.02×10^{-4}
77.0	4.21×10^{-4}
105.9	2.99×10^{-3}

If plotted graphically, the above values of Wiedmann (1972) follow the equation: $\log p = 13.3052 - A/T$, where $A = 5988.39 \pm 275.51$ (p = pressure in torr, T = temperature in °K).

Corrosivity: Noncorrosive

Flammability: Nonflammable

Formation of Clathrates and Inclusion Complexes: In general clathrates and inclusion complexes are readily formed by ureas upon crystallization (Finar, 1971). The practical consequence is the difficulty in removing impurities by recrystallizing.

Analytical Methods

This subsection reviews analytical methods for monuron. The review describes multi-residue methods, residue analyses, and formulation analyses. Available information concerning sensitivity and selectivity is also presented.

Multi-Residue Methods - Monuron has not been reported as a significant residue in any class of food nor is it routinely searched for in the Food and Drug Administration (FDA) multi-residue analytical system which is used to monitor pesticide residues in food. The apparent reason for the absence of monuron residue data is that the herbicide is not used on food and feed items. However, individual compound methods exist for measuring monuron residues. The Pesticide Analytical Manual (PAM, Vol. I, 1971) contains data on the recovery of monuron following extraction and cleanup. PAM also lists relative retention times and responses.

Residue Analysis - PAM (Vol. II, 1971) lists 3 methods of residue analysis. The first is the method of Dalton and Pease (1962), and is applicable to residues of monuron and related urea herbicides. This method involves quantitative alkaline hydrolysis of the substituted ureas to the aromatic amines, with simultaneous partitioning into an organic solvent. The amines are then extracted into dilute acid and determined colorimetrically after diazotization and a coupling reaction. The extracts are separated on a cellulose column and can then be analyzed for mixtures of the 4 herbicides, or for a single herbicide. Test recoveries for monuron ranged from 89 to 100% on asparagus, sugarcane and several types of fruit, with residues in the range of 0.04 ppm to 3.2 ppm.

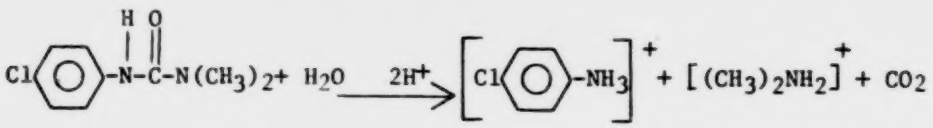
The second method is from Major (1962). It is a qualitative and semi-quantitative method designed to be used as a screening procedure for monuron and related urea herbicides. This method does not involve conversion to another product. After extraction and cleanup of the residue, a paper chromatographic procedure is employed in which the size and position of spots of the unknown are compared with those of standards. The authors reported 90 to 100% recoveries with detection as low as 0.5 ppm.

The third method is from Katz (1966) who describes both a quantitative and a qualitative method. Both methods are for residues of monuron and related urea herbicides in surface waters. In the quantitative method the herbicide is extracted from water with chloroform and hydrolyzed under reflux conditions with 6N HCl. The resulting aniline is diazotized and condensed with N-(1-naphthyl)-ethylenediamine to form a magenta dye, which is extracted with n-butanol and measured colorimetrically at 555 nm. Levels as low as 0.03 ppm monuron were detected. Qualitative determination is made by TLC. The herbicide is extracted from water with chloroform, and the volume is reduced. After development, the chromatograms are sprayed with ninhydrin and visualized.

Lowen et al. (1964) noted that monuron and other urea herbicides are determined by hydrolysis to the corresponding aromatic amine (p-chloroaniline) and then isolated from the substrate by distillation. Determination of the amine can then be made by 4 methods described by Lowen et al. (1964). The first amine method is the colorimetric method of Bleidner et al. (1954). This is the predecessor of the previously described method of Dalton and Pease (1962), but it is for monuron only. For example, it does not involve the separation technique of Dalton and Pease. The second method from Bleidner (1954) may be used for soil and plant tissue residues. This colorimetric procedure employs a simple technique for removing an interfering azo dye. The interfering dye is formed from o-aminoacetophenone, a compound resulting from the hydrolysis of naturally occurring material (tryptophan). The removal of the interfering dye is accomplished by a separation procedure using a cellulos column. The other 2 methods for amine determination described by Lowen et al. (1964) are for multi-substituted urea residues. The programmed-temperature gas chromatography method of Kirkland (1962) can determine monuron and another urea herbicide simultaneously and has been employed for analyses of residues on fruits, vegetables, and soil in the 0.1 to 1.5 ppm range. The colorimetric method of Pease (1962) allows for simultaneous detection of monuron and another urea herbicide residues by a column chromatographic procedure which separates the corresponding azo dyes by an extension of the Bleidner method. Recoveries were greater than 90% in the 0.06 to 3.0 ppm range on asparagus, sugarcane and various fruits.

Zweig and Sherma (1972) described the method of Gutenmann and List (1964), which involves extraction of the residue with acetone and partitioning into hexane. Bromination is then done simultaneously with the hydrolysis step. The brominated aniline is then determined by electron-affinity gas chromatography. Bromo compounds have a much greater electron affinity than chloro compounds. Monuron was tested in grapes, for which the recoveries ranged from 79 to 107%. Sensitivity of the method is about 0.02 ppm.

Formulation Analysis - Lowen et al. (1964) described 2 methods of formulation analysis. One method is from Lowen and Baker (1952). This method involves hydrolysis of the monuron to dimethylamine. Lowen and Baker note that acid of alkaline hydrolysis may be employed, but Lowen et al. (1964) recommends the acid hydrolysis, as shown in the following equation:



(13)

The dimethylamine is determined by back-titrating with standard caustic. Lowen and Baker (1952) report a standard deviation of 0.16% in analyzing technical grade monuron. The method is limited to samples containing no basic materials or compounds capable of forming bases during acid hydrolysis.

The disadvantage of the Lowen and Baker (1952) method is that hydrolysis with 0.1 N H_2SO_4 takes 13 hr, although little operator time is required. If stronger acid is used, the end point of the titration becomes obscure. Yuen and Palmer (1972) were able to reduce the hydrolysis time to 1/2 hr by using 24 N H_2SO_4, and then locating the end-point potentiometrically. This variation of the method was applied to technical monuron and aqueous suspension formulations with an error of 0.9%.

The second method mentioned by Lowen et al. (1964) is from Kirkland (1955). Kirkland's method involves infrared spectrophotometric analysis using a potassium bromide disk. Results of analysis of several samples are presented, but no conclusion on accuracy is made.

Composition and Formulation

Monuron is available in 2 kinds of formulations, wettable powders and granular forms. The most common formulation is 80% wettable powder. There are several granular formulations which contain from 2.4 to 8% active ingredient (AI). A water suspension containing 2.8 lb/gal AI was once manufactured, but it is no longer available. Granular formulations containing monuron-TCA (trichloroacetic acid) as the active ingredients are available in several strengths from Allied Chemical Corporation.

Monuron is compatible with other agricultural chemicals such as sodium metaborate, sodium tetraborate, and sodium chlorate and is sold in combination with them.

Chemical Properties, Degradation and Decomposition Processes

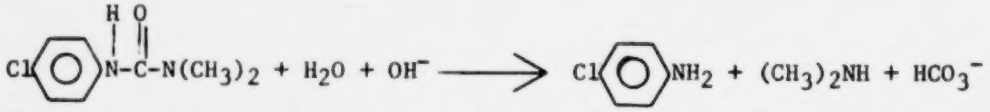
As a general proposition, monuron, being a N-aryl urea, will methylate at the N or O position with various methylating agents (Finar, 1971). It will demethylate biologically in plants and mammals (Menzie, 1969 and 1974) through N-hydroxymethyl and N-formyl intermediates. The N-formyl intermediate was also observed as a photo product.

Most of the available information concerning the degradation and decomposition reactions of monuron is contained in articles on losses that occur when the product is used as a herbicide. Monuron must reach and enter the roots of a plant in order to destroy it. There are many ways that monuron may be lost before entering the roots. The primary methods of loss are: chemical decomposition, (by oxidation or hydrolysis, for example) photodecomposition, evaporation (volatilization), leaching through the soil by water, and decomposition by soil microorganisms.

The available information concerning chemical decomposition, photodecomposition, and evaporation is summarized in this section; leaching and decomposition by soil microorganisms are discussed in the Fate and Significance in the Environment section, p. 71.

There is some disagreement as to which method of loss is the more important. Hill et al. (1955) studied the rate of disappearance of several substituted urea herbicides (primarily monuron) on several types of soil under field conditions. They concluded that volatilization, leaching and chemical decomposition are very minor causes of disappearance. Photodecomposition may be an important factor where there is little rainfall. However, according to these investigators, the primary cause of disappearance is microbiological decomposition.

Lowen et al. (1964) reported that monuron is stable toward oxidation and hydrolysis under normal conditions, but at elevated temperatures they can be hydrolyzed quantitatively. Martin (1971) adds that the hydrolysis rate increases in acid or alkaline conditions. The equation for alkaline hydrolysis is as follows:



(12)

The equation for acid hydrolysis Number 13 is shown in the Analytical Methods subsection.

Hance (1965) reported that a herbicide with a molecular weight of about 180 and a vapor pressure of about 10^{-4} mm Hg could be lost from the soil surface by evaporation at an approximate rate of 24 lb/acre/month. On this basis, material such as monuron, which has a vapor pressure of 5×10^{-7} mm Hg at 25°C, would be 200 times less volatile, and the loss of monuron in this way would not be significant. Hance further noted that under field conditions "it is difficult to distinguish between accelerated evaporation and photochemical decomposition."

With regard to chemical decomposition, Hance stated:

> Many herbicides contain groups which are susceptible to hydrolysis. At normal soil pH values, such processes will be slow, but at the surface of soil colloids, particularly the organic colloids, the local

pH may be appreciably lower than the bulk pH of the soil and hydrolysis could then occur with significant speed. Little is known of the extent to which herbicides undergo oxidation or reduction in the soil. However, it is reasonable to suppose that the molecular distortion imposed when a molecule is absorbed may lead to increased susceptibility to oxidation by atmospheric oxygen.

Hance (1965) agreed with other sources on the proposition that microbiological breakdown is one of the most important decomposition processes. Hance also noted that leaching may move the herbicide into the desired root area, or move it out of that area.

According to Hill (1971), soil is not always the same, but its ability to degrade organic compounds depends upon such factors as temperature, pH, moisture content, amount of rainfall, and the soil fertility, texture, structure and content of organic matter. Though he provided new information on biological degradation, his conclusions were the same as noted earlier in Hill et al. (1955).

Geissbuhler (1969) contended: "Although no systematic studies have been carried out, urea herbicides appear to be sufficiently stable under normal temperature and soil conditions to resist hydrolytic breakdown or oxidation by purely chemical means."

Photodecomposition - Hill et al. (1955) reported that an 83% loss of monuron occurred when a solution containing 88.3 ppm monuron in glass-distilled water was exposed in sealed quartz tubes to sunlight for 48 days. Decomposition products were not reported.

Weldon and Timmons (1961) described an experiment in which monuron and another urea herbicide were exposed to an 85-W mercury-vapor lamp. They prepared 10 ppm solutions of the recrystallized herbicides in 95% ethyl alcohol. These solutions were scanned from 215 to 360 nm using a spectrophotometer. After evaporating the alcohol from the samples in petri dishes, the residues were exposed to the lamp for periods of 0, 2, 8, and 28 hrs. Those exposed to the ultraviolet radiation for short periods of time were left exposed to air at room temperature up to the 28-hr period. The radiant energy levels emitted at various wavelengths by the lamp were as follows:

	Wavelength (nm)	Radiant Energy (W)
Far ultraviolet	220-280	0.73
Middle ultraviolet	280-320	3.70
Near ultraviolet	320-400	5.07
Visible	400-760	8.93

After exposure, the residues were redissolved in ethyl alcohol and again scanned with the spectrophotometer.

For monuron, the largest changes in percent transmittance occurred at 245 and 220 nm. The other urea herbicide underwent more extensive photochemical change than monuron. No explanations were proposed concerning the chemical changes which were caused by the ultraviolet radiation.

In a variation of the above experiment, Weldon and Timmons (1961) measured the effects on oat growth of 28-hr irradiated and nonirradiated monuron. These samples were prepared as in the experiment previously described. Their data indicated a 75% reduction in biological activity of irradiated, as compared to nonirradiated, herbicide. Weldon and Timmons (1961) did not identify any chemical products from the effects of irradiation.

In another photochemical study, Jordan et al. (1965) investigated the effect of ultraviolet (UV) radiation on herbicides. They subjected samples of monuron and several other herbicides to various sources of UV radiation. Three sources of UV radiation were used: far UV (wavelength range, 240 to 260 nm, peak at 253.7 nm); middle UV (275 to 375 nm, peak at 311 nm) and near UV (320 to 450 nm, peak at 360 nm). The lamps emitted approximately 15 W at the peak wavelength. The samples were prepared by allowing solutions (1×10^{-3} molar) to evaporate on 1 in diameter aluminum planchets. The samples were placed 1 ft from the UV sources.

Examination of the UV absorption spectra showed that the most extensive decomposition of monuron was caused by far-UV radiation. The greatest decreases in absorbance for monuron occurred at 240 to 260 and 205 to 215 nm. However, a thin layer of decomposed product apparently protected the lower layers, indicating that very little protection is required to prevent photodecomposition in this instance. The author noted that far-UV radiation does not remain in natural sunlight reaching the earth's surface. However, there is significant UV radiation in sunlight above 290 nm and the photodecomposition mechanism is probably the same at all UV wavelengths. Similar results obtained by Wright (1967) indicated that far-UV radiation produces more rapid decomposition of monuron than middle- or near-UV radiation.

The products of monuron photodecomposition have also been investigated. One of the most extensive studies was that of Crosby and Tang (1969). Their irradiation experiments were done using a 200 ppm solution of monuron in deionized water. Some samples were held under aerobic conditions and some under anaerobic conditions. Some samples were exposed to sunlight for 14 days (during which 6% of the monuron decomposed), and others were exposed to a 40-W G.E. F40BL blacklight-fluorescent lamp for 7 days. Blacklight-fluorescent lamps emit ultraviolet radiation in the middle-UV range in a broad band around 366 nm. They emit practically no radiation in the far-UV range. The results indicated a close similarity between decomposition by sunlight and ultraviolet lamp radiation. Several extracts of the irradiated solutions were analyzed by thin layer chromatography (TLC). Photoproducts were identified by comparison of their spectral or chromatographic properties with those of authentic standards. Table 1 lists the photodecompsoition products of monuron. Figure 1 shows the reaction scheme proposed by Crosby and Tang (1969) to account for some of these products.

Table 1. PHOTODECOMPOSITION PRODUCTS OF MONURON

Compound	Structure
Monuron	A
3-(p-chlorophenyl)-1-formyl-1-methylurea	B
1-(p-chlorophenyl)-3-methylurea	C
1-(p-chlorophenyl)-3-formylurea[a]	D
p-chlorophenylurea[a]	E
3-(p-chloro-o-hydroxy-phenyl)-1,1-dimethylurea	F
4,4'-dichlorocarbanilide	G
p-chloroformanilide[a]	H
p-chloroaniline[a]	I
p-hydroxyphenyl urea	J (one month)

---

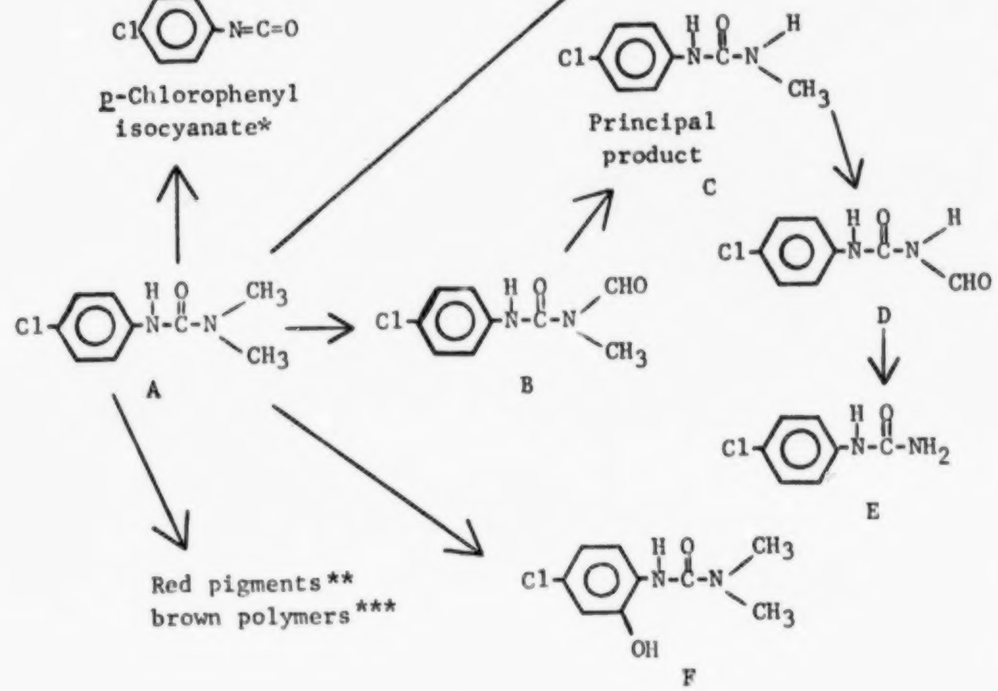
[a] Chromatographic and chromogenic identification only.

Compound C was the principal product. The conversion of Products B and D into C and E, respectively, did not occur when the compounds were irradiated on a dry chromatoplate. Thus, these reactions appear to require the presence of water. These reactions are also very slow in the absence of light.

Crosby and Tang (1969) noted that the oxidation of p-chloroaniline forms a red compound, but the mass spectrum of their red pigment was not conclusively shown to be the same as that from the oxidation of p-chloroaniline. The brown polymers observed by Crosby and Tang (1969) were reported to be similar to humic acid.

Further biological decomposition of p-chloroaniline apparently occurs in the soil. The microbial degradation of monuron, as well as further reaction of some of its initial degradation products (e.g., oxidation of p-chloroaniline), are discussed in the Fate and Significance in the Environment section of this report (p. 71).

Crosby and Tang (1969) concluded that replacement of the aromatic chlorine of monuron represented a minor reaction, if it occurred at all. These investigators found no evidence of a hydroxy compound among the decomposition products, and they noted that the pH did not change (approximately pH 8), indicating that no hydrogen chloride was formed.



Cl
N=C=O
p-Chlorophenyl isocyanate*
G
I
H
Principal product
C
D
E
A
B
F
Red pigments**
brown polymers***

Figure 1. Proposed photodecomposition reaction sequence of monuron in aqueous solution under aerobic conditions.

* Possible intermediate.
** Characterized by indoanilineamine.
*** Characterized by homic acid.

Source: Adapted from Crosby and Tang (1969); Rosen (1969); and Sweetser (1963).

Under anaerobic conditions, the rate of photodecomposition was greatly reduced. The investigators therefore concluded that photooxidation represents by far the most important route of monuron photodecomposition.

Rosen et al. (1969) investigated the photolysis of phenylurea herbicides, including monuron. They exposed aqueous samples containing 55 ppm herbicide to sunlight for 17 days. Because they knew of the work of Crosby and Tang (1969), they did not attempt to identify most of the monuron decomposition products. They did find one new product that co-chromatographed with, and had the same infrared spectrum as, 3-(p-hydroxyphenyl)-1,1-dimethylurea. As noted above, Crosby and Tang (1969) were unable to find any hydroxy compound.

Hill (1971) recognized the photodecomposition work of previous investigators, but noted that all of the work involved laboratory tests. He commented that, under field conditions, photodecomposition was not found to be a major factor in the disappearance of monuron from the soil.

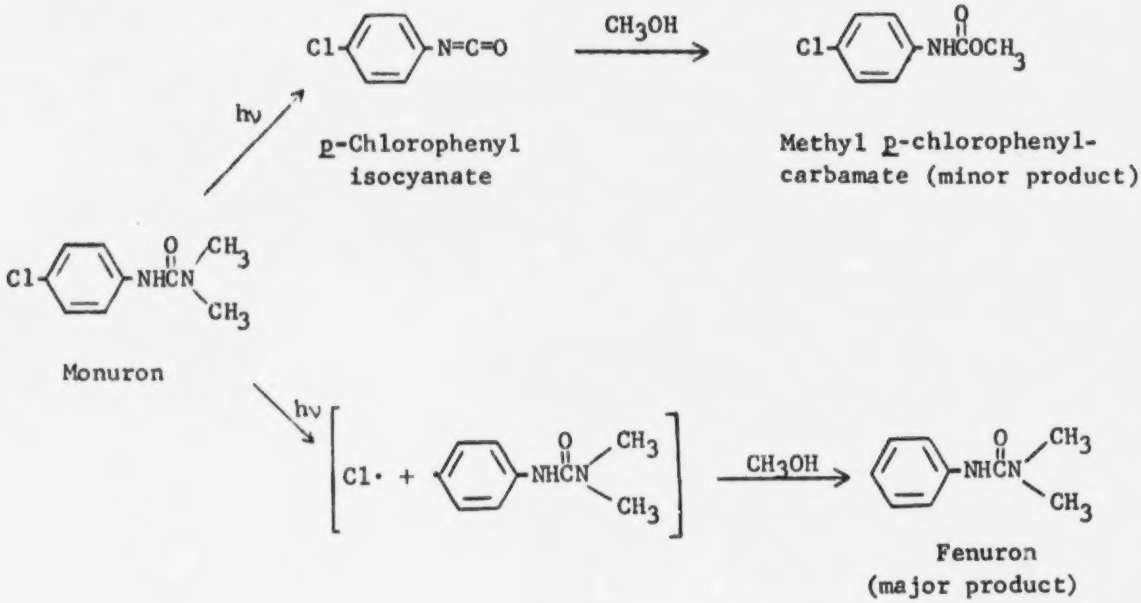
Mazzocchi and Rao (1972) then investigated the photodecomposition products of fenuron by irradiating it (in methanol solution) for 13 days. Figure 3 shows the degradation products of fenuron. Since fenuron is a photodegradation product of monuron, the products illustrated are actually ultimate degradation products of monuron. However, the authors note that the rate of photodegradation of monuron is about 4 times the rate of photodegradation of fenuron. This difference in rate explains the fact that, in the photodecomposition of monuron, there is a buildup of fenuron.

Figure 2 shows the degradation products and the proposed mechanisms of Mazzocchi and Rao. Note that HCl was formed. Fenuron was the major degradation product of monuron. These photodecomposition products are entirely different from those reported by Crosby and Tang (1969) who employed aqueous solutions. (See Table 1 and Figure 1.)

Mazzocchi and Rao (1972) then investigated the photodecomposition products of fresh fenuron by irradiating it (in methanol solution) for 13 days. Figure 3 shows the degradation products of fenuron. Since fenuron is a photodegradation product of monuron, the products illustrated are actually ultimate degradation products of monuron. However, the authors note that the rate of photodegradation of monuron is about 4 times the rate of photodegradation of fenuron. This difference in rate explains the fact that, in the photodecomposition of monuron, there is a buildup of fenuron.

In their discussion of results, Mazzocchi and Rao (1972) noted that their results did not agree with the results of other investigators. Since their tests were carried out under artificial laboratory conditions (anaerobically in methanol), their results have little relevance to photodegradation in the natural environment.

Other Properties and Reactions - Cluett (1962) titrated certain substituted phenylureas, including monuron, as acids in n-butylamine, with a titrant



hν
CH3OH
p-Chlorophenyl isocyanate
Methyl p-chlorophenylcarbamate (minor product)
Monuron
hν
Cl· +
CH3OH
Fenuron (major product)

Figure 2. Photolysis of monuron in methanol under anaerobic conditions.

Source: Adapted from Mazzocchi and Rao (1972).

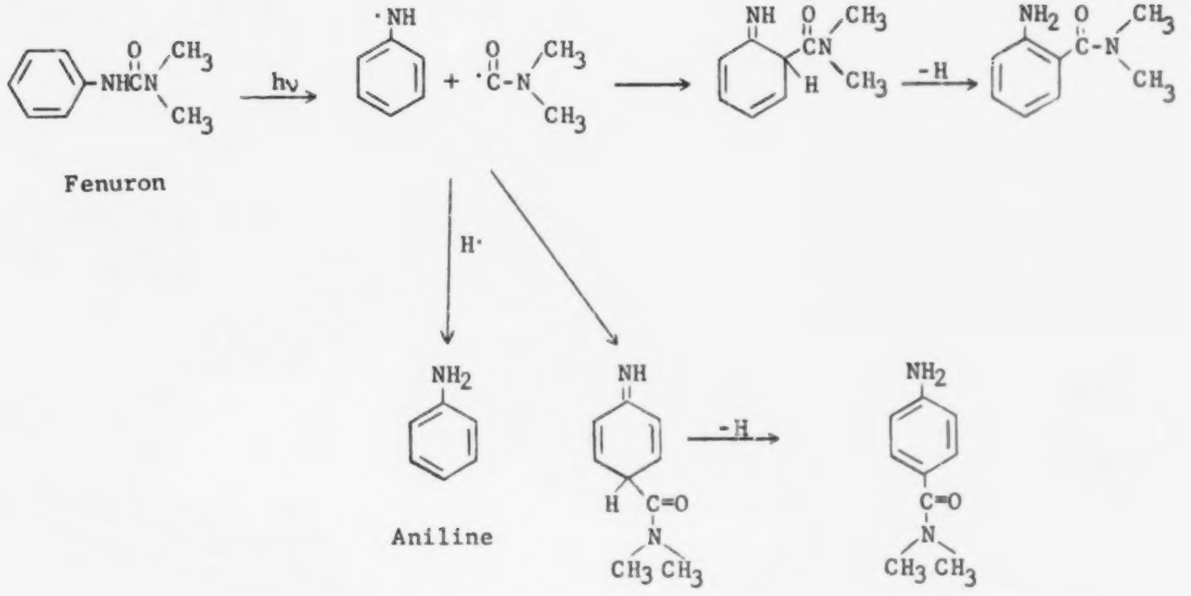

Fenuron
hν
H·
-H
-H
Aniline

Figure 3. Photolysis of fenuron in methanol under anaerobic conditions.

Source: Adapted from Mazzocchi and Rao (1972).

of 0.1 N tetra-n-butylammonium hydroxide and methoxide in 9:1 benzene-methanol solution. These titrations were performed potentiometrically and followed photometrically and conductimetrically. From this data, a table of relative acidity as measured by half-neutralization potentials in millivolts was prepared (the lower the potential, the stronger the acid). Cluett presented data for many substituted phenylureas, some of which are shown below together with data for 2 common acids for comparison:

Compound	Half-neutralization potential (mv)
Phenylurea	870
Monuron	745
Benzoic acid	500
HCl	420

Lee and Fang (1971) determined that, when monuron is extracted from spinach by Soxhlet extraction with ethanol, the monuron was converted to ethyl p-chlorophenylcarbamate.

Occurrence of Residues in Food and Feed Commodities

The Food and Drug Administration (FDA), Department of Health, Education, and Welfare, monitors pesticide residues in the nation's food supply. There are two programs; one is commonly known as the "total diet program," the other is called a "market basket" study.

Monuron has not been reported as a significant residue in any food class, nor is it routinely searched for in the FDA multi-residue analytical system which is used to monitor pesticide residues in food. The pesticide is no longer used on food items.

Acceptable Daily Intake

The acceptable daily intake (ADI) is defined as the daily intake which, during an entire lifetime, appears to be without appreciable risk on the basis of all known facts at the time of evaluation (Lu, 1973). It is expressed in milligrams of the chemical per kilogram of body weight (mg/kg).

The ADI is established by the Food and Agricultural Organization/World Health Organization (FAO/WHO). An ADI has not yet been determined for monuron.

Tolerances

Due to inadequate toxicity data to support the safety of tolerances, EPA revoked all previous tolerances for monuron, effective July 26, 1973 (Federal Register, 1973). Residue tolerances in effect at the time of the revocation were 7 ppm for asparagus, and 1 ppm on the following crops: avocados, cottonseed, grapes, dry bulb onions, pineapples, spinach, sugarcane, and citrus fruits including oranges, lemons, limes, grapefruit, kumquats, tangerines, and citron (Federal Register 1955, 1956, 1957).

References

Bleidner, W. E., "Application of Chromatography in Determination of Micro Quantities of 3-(*p*-Chlorophenyl)-1,1-dimethylurea," *J. Agr. Food Chem.*, (13):682-684 (1954).

Bleidner, W. E., H. M. Baker, M. Levitsky, and W. K. Lowen, "Determination of 3-(*p*-Chlorophenyl)-1,1-dimethylurea in Soils and Plant Tissue," *J. Agr. Food Chem.*, 2(9):476-479 (1954).

Cluett, M. L., "Study of the Titration of Selected Substituted Phenylureas, as Acids in *n*-Butylamine," *Anal. Chem.*, 34(11):1491-1495 (October, 1962).

Crosby, D. G., and C. S. Tang, "Photodecomposition of 3-(*p*-Chlorophenyl)-1,1-demethylurea (Monuron)," *J. Agr. Food Chem.*, 17(5):1041-1044 (September-October, 1969).

Dalton, R. L., and H. L. Pease, "Determination of Residues of Diuron, Monuron, Fenuron, and Neburon," *J. Ass. Offic. Agr. Chem.*, 45(2):377-381 (1962).

Finar, J. L., *Organic Chemistry*, Vol. I., Longmane, London (1971).

Geissbuhler, H., "The Substituted Ureas," *Degradation of Herbicides*, P. C. Kearney and D. D. Kaufman (eds.), Marcel Dekker, New York (1969).

Gutenmann, W. H., and D. J. Lisk, "Electron Affinity Residue Determination of CIPC, Monuron, Diuron, and Linuron by Direct Hydrolysis and Bromination," *J. Agr. Food Chem.*, 12(1):46-48 (1964).

Hance, R. J., "Soil-Applied Herbicides," *Report of the Aeronautical Research Council Weed Research Organization*: 1960-1964, London, pp. 20-26 (1965).

Hearsey, C. J., and B. D. Mehta (to Quimco G.m.b.H.), Ger. Offen. 2,258,453 (June 14, 1973).

Hill, G. D., J. W. McGahen, H. M. Baker, D. W. Finnerty, and C. W. Bingeman, "The Fate of Substituted Urea Herbicides in Agricultural Soils," *Agron. J.*, 47:93-104 (1955).

Hill, G. D., "Characteristics of Herbicides by Chemical Groups," *Proc. Annual Calif. Weed Conf.*, 23:158-170 (1971).

Hurle, K. B., and V. H. Freed, "Effect of Electrolytes on the Solubility of Some 1,3,5-Triazines and Substituted Ureas and Their Absorption on Soil," *Weed Res.*, 12(1):1-10 (March, 1972).

Jones, R. L. (to Imperial Chemical Industries), U.S. Patent No. 2,768,971 (October 30, 1956).

Jordan, L. S., J. D. Mann, and B. E. Day, "Effects of Ultraviolet Light on Herbicides," *Weeds*, 13(11):43-46 (January, 1965).

Julian, F. M., and H. T. Siefen (to E. I. du Pont de Nemours and Company) U.S. Patent No. 2,974,163 (1961).

Katz, S. E., "Determination of the Substituted Urea Herbicides Linuron, Monuron, Diuron, Neburon, and Fenuron in Surface Water," J. Ass. Offic. Anal. Chem., 49(2):452-456 (1966).

Kirkland, J. J., "Quantitative Application of Potassium Bromide Disk Technique in Infrared Spectroscopy," Anal. Chem., 27(10):1537-1541 (October, 1955).

Kirkland, J. J., "Trace Analysis by Programmed Temperature Gas Chromatography, Simultaneous Determination of Monuron and Diuron Herbicide Residues," Anal. Chem., 34(3):428-433 (March, 1962).

Lee, S. S., and S. C. Fang, "Conversion of Monuron to Ethyl-N-p-chlorophenyl Carbamate by Soxhlet Extraction of Plant Tissue with Ethanol," J. Ass. Offic. Anal. Chem., 54(6):1361-1365 (1971).

Lowen, W. K., and H. M. Baker, "Determination of Macro and Micro Quantities of 3-(p-Chlorophenyl)-1,1-dimethylurea," Anal. Chem., 24(9):1475-1479 (September, 1952).

Lowen, W. K., W. E. Bleidner, J. J. Kirkland, and H. L. Pease, "Monuron, Diuron, and Neburon," Analytical Methods for Pesticides, Plant Growth Regulators, and Food Additives, Vol. IV: Herbicides, G. Zweig (ed.), Academic Press, New York (1964).

Lu, F. C., "Toxicological Evaluation of Food Additives and Pesticide Residues and Their 'Acceptable Daily Intakes' for Man: The Role of WHO, in Conjunction with FAO," Res. Rev., 45:81-93 (1973).

Major, A., Jr., "Screening Method for Monuron, Diuron, and Neburon Residues on Fruits and Vegetables by Paper Chromatography," J. Ass. Offic. Agr. Chem., 45(2):387-390 (1962).

Martin, H., Pesticide Manual, 2nd ed. British Crop Protection Council, Clack Farm, Boreley, Ombersley, and Droitwich, Worcestershire, (1971).

Martin, H., The Scientific Principles of Crop Protection, St. Martin's Press, New York (1964).

Mazzocchi, P. H., and M. P. Rao, "Photolysis of 3-(p-Chlorophenyl)-1,1-dimethylurea (Monuron) and 3-Phenyl-1,1-dimethylurea (Fenuron)," J. Agr. Food Chem., 20(5):957-959 (1972).

Melnikov, N. N., Chemistry of Pesticides, Vol. 36 of Res. Rev., (1971).

Menzie, C. M., Metabolism of Pesticides, U.S. Department of the Interior, Fish and Wildlife Service, Bureau of Sport Fisheries and Wildlife, Special Scientific Report - Wildlife No. 127, Washington, D. C. (1969).

Menzie, C. M., Metabolism of Pesticides, An Update, U.S. Department of the Interior, Fish and Wildlife Service, Bureau of Sport Fisheries and Wildlife, Special Scientific Report - Wildlife No. 184, Washington, D. C. (1974).

Merck Index, The, 8th ed., P. J. Strecher (ed.), Merck and Company, Rahway, New Jersey (1968).

"Monuron Revocation", Federal Register, 38(122):16730 (June 26, 1973).

Pease, H. L., "Separation and Colorimetric Determination of Monuron and Diuron Residues," J. Agr. Food Chem., 10(4):279-281 (1962).

Pesticide Chemical News Guide, The, Food Chemical News (May 1, 1974).

Rosen, J. D., R. F. Strusz, and C. C. Still, "Photolysis of Phenylurea Herbicides," J. Agr. Food Chem., 17(2):206-207 (1969).

Searle, N. E., and C. W. Todd (to E. I. du Pont de Nemours and Company), U.S. Patent No. 2,663,729 (December 22, 1953).

Sittig, M., Pesticide Production Processes, Chemical Process Review No. 5, Noyes Development Corporation, Park Ridge, New Jersey (1967).

Sittig, M., Agricultural Chemicals Manufacture, Chemical Process Review No. 52, Noyes Data Cooperation, Park Ridge, New Jersey (1971).

Stanford Research Institute, 1974 Directory of Chemical Producers, J. L. Blackford (ed.), Menlo Park, California (1974).

Sweetser, P. B., "Photoinactivation of Monuron, 3-(p-Chlorophenyl)-1,1-dimethylurea, by Riboflavin S Phosphate", Biochimica et Biophysica Acta, 66:78-85 (1963).

Thompson, W. (to E. I. du Pont de Nemours and Company) U.S. Patent No. 2,673,877 (1954).

Todd, C. W. (to E. I. du Pont de Nemours and Company) U.S. Patent No. 2,644,447 (October 13, 1953).

"Tolerances for Residues of 3-(p-Chloro-phenyl)-1,1-Dimethylurea", Federal Register, 20:7301-7302 (September 30, 1955).

"Tolerances for Residues of 3-(p-Chloro-phenyl)-1,1-Dimethylurea," Federal Register, 21:2614 (April 4, 1956).

"Tolerances for Residues of 3-(p-Chloro-phenyl)-1,1-Dimethylurea," Federal Register, 21:5046 (July 7, 1956).

"Tolerances for Residues of 3-(p-Chloro-phenyl)-1,1-Dimethylurea," Federal Register, 22:10017 (December 13, 1957).

U.S. Department of Health, Education, and Welfare, Food and Drug Administration, Pesticide Analytical Manual, 2 Vols. (1971).

Weldon, L. W., and F. L. Timmons, "Photochemical Degradation of Diuron and Monuron," Weeds, 9(1):111-116 (1961).

Wiedemann, H. G., "Applications of Thermogravimetry for Vapor Pressure Determination," Thermochimica Acta, 3(5):355-366 (1972).

Wright, W. L., "Photochemical Breakdown of Herbicides (abstract)," Proceedings 20th Southern Weeds Conference, 20:391 (1967).

Yuen, S. H., and J. M. C. Palmer, "Potentiometric Determination of Monuron in Herbicide Formulations," Analyst, 97(1160):921-922 (November, 1972).

Zhuravlev, E. Z., "The Solubility of Monuron and Diuron in Water," Agrokimiya, pp. 141-143 (1969).

Zweig, G., and J. Sherma, Analytical Methods for Pesticides and Plant Growth Regulators, Vol. VI: Gas Chromatographic Analysis, Academic Press, New York, New York (1972).

PART II. INITIAL SCIENTIFIC REVIEW

SUBPART B. PHARMACOLOGY AND TOXICOLOGY

CONTENTS

Page

Acute, Subacute and Chronic Toxicity 36

  Toxicity to Laboratory Animals. 36

    Acute Oral Toxicity - Rats 36
    Approximate Lethal Dose - Rats 36
    Approximate Lethal Dose - Guinea Pigs. 37
    Approximate Lethal Dose - Rabbits. 37
    Subacute Oral Toxicity - Rats. 37
    Chronic Oral Toxicity - Rats 38
    Chronic Oral Toxicity - Dogs 38
    Acute Dermal Toxicity - Rabbits. 39
    Primary Irritation and Skin Sensitization - Guinea Pigs. 39

Symptomology and Pathology Associated with Mammals 39

  Toxicity to Domestic Animals. 39

    Acute Toxicity - Goats 39
    Subacute Toxicity - Sheep. 40
    Subacute Toxicity - Cattle 40
    Subacute Toxicity - Chickens 40

Metabolism 41

Effect on Reproduction 43

Teratogenic Effects. 43

Oncogenesis. 43

Mutagenic Effects. 47

Effects on Humans. 47

References 48

This section reviews pharmacological and toxicological data on monuron. The acute, subacute and chronic toxicity data for a number of species by various routes of administration is discussed. Data is presented on metabolism, effects on reproduction, and teratogenic, oncogenic and mutagenic effects. Human exposure to monuron is also considered. The section summarizes rather than interprets data reviewed.

Acute, Subacute, and Chronic Toxicity

Toxicity to Laboratory Animals -

Acute Oral Toxicity - Rats - The acute oral LD_{50} toxicity of monuron to male albino rats (10 per test group) was determined to be 3,600 mg/kg body weight with confidence limits of 2,800 to 4,400 mg/kg (Zapp 1955). All of the rats which died suffered from pulmonary edema and congestion which was frequently accompanied by anemia of liver, kidneys, and spleen. Rats which survived showed signs of methemoglobinemia, such as cyanosis, enlarged dark spleen, and compensatory red blood cell (RBC) formation in the spleen and bone marrow. Some of the survivors also showed kidney pathology, possibly due to the test dose of monuron.

Another LD_{50} value for acute oral toxicity of monuron to rats was reported to be 3.4 g/kg (Hodge et al., 1957).

The results of a study by Boyd and Dobos (1969) indicated that the LD_{50} of monuron (94%) to male albino rats was 1.48 ± 0.21 g/kg when fed a standard laboratory feed. In the same study, it was shown that the lethal action of monuron varied with the amount and the nature of protein in the diet. The test animals were fed various diets from weaning to the test age of 2 months. The rats fed diets containing 3.5% casein were 3 times as susceptible to the toxic effect of monuron as rats fed a normal (26%) casein diet (LD_{50} of 0.95 g/kg versus 2.88 g/kg).

The clinical toxicity signs for doses of monuron in the range of the oral LD_{50} were essentially similar, regardless of the type of diet which had been fed.

The LD_{50} was higher in rats fed from weaning on a purified diet containing normal amounts of protein such as casein than in rats fed normal amounts of protein such as laboratory feed.

Approximate Lethal Dose - Rats - The approximate lethal dose (ALD) of monuron for male albino rats was found to be 7,500 mg/kg body weight when administered by stomach tube as a 10 or 30% suspension of monuron in peanut oil containing 20% acetone (Zapp, 1955).

Rats receiving sublethal doses became weak, pale, cyanotic, and were frequently paralyzed in the hind legs. Higher doses resulted in labored respiration, marked weakness, and unconsciousness. Rats which survived were sacrificed 10 weeks after treatment and were found to have enlarged, dark, and congested spleens containing foci of blood formation. Blood destruction and increased erythropoiesis were indicated.

Approximate Lethal Dose - Guinea Pigs - The ALD of monuron for guinea pigs was determined to be 670 mg/kg body weight. Monuron was administered by stomach tube as a 30% suspension. Sublethal doses resulted in marked weakness and loss of weight. Lethal dose signs were weakness and paralysis with slow respiration and lacrimation. Surviving animals, sacrificed 10 to 12 days posttreatment, showed no significant signs of toxicity, although one guinea pig showed evidence of a healed kidney injury (Zapp, 1955).

Approximate Lethal Dose - Rabbits - The ALD for rabbits was determined to be 1,500 mg/kg body weight. Animals administered oral doses of 200 and 450 mg/kg, as a 20% suspension in peanut oil, showed no clinical signs and no abnormal pathology when sacrificed at 12 days posttreatment. Weakness and a loss of appetite were observed in rabbits receiving oral doses of 670 and 1,000 mg/kg. Posttreatment sacrifice of survivors after 10 days indicated no significant pathological changes. Animals receiving lethal doses became unconscious shortly after treatment and died within 20 hr (Zapp, 1955).

Subacute Oral Toxicity - Rats - Doses of 1,500 mg/kg (1/5 ALD) were administered by stomach tube to 6 male albino rats, 5 times a week. By the eighth treatment, all 6 animals had died. During treatment the animals showed discomfort, weakness, and continuous weight loss. Autopsy revealed pulmonary edema and congestion as well as damage to liver, kidneys, and spleen (Zapp, 1955).

Because of the severe cumulative toxicity at 1,500 mg/kg, the subacute dose was reduced to 500 mg/kg, 5 times per week for 2 weeks. Animals showed discomfort after treatment, lost weight continuously, and became cyanotic. During the posttreatment observation period, weight was regained to almost the original level. At 10 days posttreatment, all animals were sacrificed. Spleens were large, dark, and congested with small foci of blood formation in all cases. Deposition of brown granules of blood pigment (hemosiderin) in spleens was indicative of blood destruction.

In another subacute oral study, Zapp used 3 test groups of rats (5 males and 5 females per group). Monuron was incorporated into ground laboratory feed and fed at test levels of 0.005, 0.05, and 0.5%. Food consumption in the test group was measured and compared to a control group fed the same ration but without monuron. Blood counts were performed after 1 month's feeding, and the experiment was terminated at 6 weeks.

In the group that received the 0.005% level of monuron, food consumption and weight gain were comparable to the control group; blood counts were normal, and no clinical signs were observed. After sacrifice, 2 of 5 males showed evidence of methemoglobinemia and/or compensatory RBC formation. No females showed significant pathology.

In the 0.05% group, feed consumption and weight gain for the test group was comparable to the controls. No clinical signs were observed and blood counts were within normal ranges. At sacrifice, signs of methemoglobinemia were apparent, and compensatory RBC formation was found in the spleen.

The 0.5% group consumed much less food, and consequently gained much less weight than the other test groups or controls. The animals were pale and cyanotic with lowered blood counts. The blood was dark brown and contained many degenerate RBC's. At necropsy methemoglobinemia was apparent as well as possible blood destruction. Compensatory RBC formation was found in the spleen and bone marrow of all animals. No mortality occurred, even at the highest level fed (0.5%).

Chronic Oral Toxicity - Rats - Four groups of 60 Rochester strain rats (30 male and 30 female rats per group) were fed for 2 yr on diets containing monuron at concentrations of 0 (controls), 25, 250, and 2,500 ppm (Hodge et al., 1958). Throughout the feeding period, diets and tap water were supplied *ad libitum*.

Both male and female rats fed 25 and 250 ppm monuron showed no differences in weight gain over the 2 yr period as compared to the control group. Male rats fed 2,500 ppm monuron showed a growth retardation of 20 g after the first month and maintained a moderate weight differential throughout the experimental period. Female rats fed 2,500 ppm monuron showed a similar but less marked differential throughout the feeding trial.

Although 70 to 90% of the colony was lost by the end of the second year due to epidemics of upper respiratory infection, the lifespan of the surviving rats was unaffected by the feeding of monuron at all dose levels. The protein and sugar concentrations in pooled urine samples, taken throughout the 2 yr period, were found to be normal.

At the termination of the experiment, all survivors were sacrificed for pathological examination. Other than a slight increase in weights of livers and spleens from female rats fed 2,500 ppm monuron, no significant differences were noted in size and weights of individual organs from control and treated animals. Histological examination revealed no abnormalities in kidney, heart, brain, lung, spleen, liver, adrenal, bladder, gonad, stomach, intestines, and bone marrow tissues.

In addition to 30 deaths due to spontaneous tumors throughout the 2-yr period, 24 tumors of various kinds were found during necropsy of survivors. The incidence of tumors was found to be no higher in the experimental than in the control groups. The oral no-effect level for rats was determined to be 250 ppm.

Chronic Oral Toxicity - Dogs - Pairs of young beagles, consisting of 1 male and 1 female, were fed monuron for 1 yr at daily levels of 0 (controls), 2.5, 12.5, and 25.0 mg/kg body weight (Hodge et al. 1958). During the feeding period, no deaths occurred, and no adverse effect on animal health was noted. Analyses of blood and urine samples taken throughout the study indicated normal profiles.

At the time of sacrifice, organ size and weights were normal for livers, kidneys, brains, hearts, lungs, and spleens. Normal histological profiles were found for tissues of all organs examined after necropsy.

On the basis of the 1-yr chronic study on dogs, a no-effect level of monuron for dogs was determined to be 25 mg/kg body weight for long-term exposure. The no-effect level for monuron as ingested in food by dogs is 1,000 ppm.

Acute Dermal Toxicity - Rabbits - A 20% suspension of monuron in dimethyl phthalate was applied to shaved skin between the shoulders of a male rabbit. A maximum feasible dose of 2,250 mg/kg was administered over an 8-hr period by rubbing it into the skin with a glass rod. Five hours after treatment, the material was caked on the rabbit's back. The material disappeared within 2 days, and the rabbit showed no clinical signs of intoxication. No significant clinical pathology was found at sacrifice, 11 days after treatment (Zapp, 1955).

Primary Irritation and Skin Sensitization - Guinea Pigs - A 33% water paste of monuron was applied to both intact and abraded skin of male albino guinea pigs. The compound was practically nonirritating and did not cause allergic skin sensitization. No further details were given on such parameters as numbers used or period of experimentation.

The author concluded that a moderate amount of skin contact with CMU (monuron) would not be harmful because it is not an irritant or a sensitizer, nor is it significantly absorbed through the skin (Zapp, 1955).

Symptomology and Pathology Associated with Mammals - It appears that the signs of toxicity which will be observed in most animals will be similar and will consist of one or more of the following, depending on the size of the dose: loss of appetite, weakness, weight loss, diarrhea, labored respiration, lacrimation, cyanosis, ptosis, paralysis (especially handquarter), and unconsciousness. Pathological examination could show some of the following conditions: lowered blood count, methemoglobinemia, acute gastritis with inflammation and hemorrhaging, pulmonary edema, congestion of liver and kidney, and enlargement of spleen with foci of blood formation. (Zapp, 1955; Kay, 1957; Palmer and Radeleff, 1969).

Toxicity to Domestic Animals -

Acute Toxicity - Goats - Goats were given a single oral drench using a 50% aqueous slurry of 80% CMU (monuron). The results, shown in Table 2, indicate that the LD_{50} for goats falls in the range of 600 to 1,600 mg/kg body weight (E. I. du Pont de Nemours and Company 1952).

Table 2. ACUTE TOXICITY OF MONURON TO GOATS BY SINGLE DRENCH

Dose (mg/kg)	Symptoms	Mortality
3,200	Intoxicated in 2-1/2 hr	1/1 after 12 hr
1,600	Intoxicated in 2-1/2 hr	1/1 after 12 hr
600	Intoxicated in 6 hr (normal in 48 hr)	0/1
300	Intoxicated in 20 hr (normal in 48 hr)	0/1
150	No symptoms	0/1

Subacute Toxicity - Sheep - One sheep survived 10 daily doses of monuron at 50 mg/kg (by drench) with no ill effects. Of 2 sheep dosed at 100 mg/kg (by drench) one exhibited signs of poisoning after 4 doses, but survived; the other animal died after 9 doses, with a 20% weight loss. A fourth animal given 100 mg/kg by capsule for 10 doses exhibited signs of poisoning, but survived (Palmer and Radeleff, 1969).

Subacute Toxicity - Cattle - Cattle were administered monuron (80% wettable powder) in multiple daily doses from 25 mg/kg to 250 mg/kg by drench.

The animals developed diarrhea after 1 to 5 doses at 50, 100, and 250 mg/kg although no other ill effects were noted. The diarrhea was not severe enough to result in any significant weight loss.

After a single dose at a 500-mg/kg level, one yearling exhibited signs of poisoning and exhibited an 11% weight loss, but survived.

One yearling was dosed at 50 mg/kg daily by capsule for 10 days without exhibiting any diarrhea or other ill effects (Palmer and Radeleff, 1969).

Subacute Toxicity - Chickens - Chickens were administered monuron (80% wettable powder) in capsules in doses from 10 mg/kg to 250 mg/kg for up to 10 days.

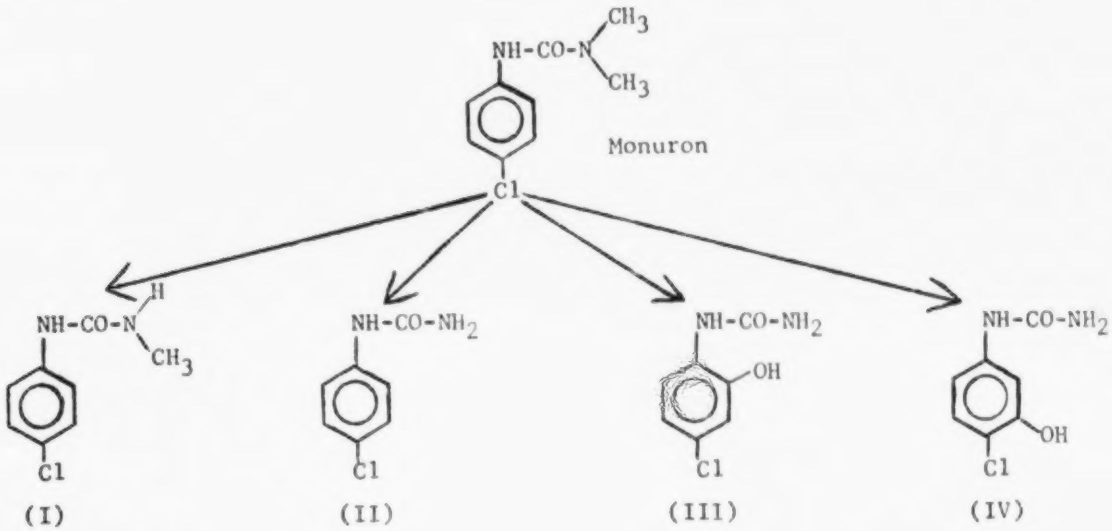
When treated chickens were compared to controls the 10-mg/kg dose was found to have had no effect on weight gain. At 25 mg/kg, the chickens exhibited a weight gain 14% lower than that attained by controls. At a dosage of 50 mg/kg, treated chickens had a weight gain 27% below the gain of untreated controls.

When the dosage was 100 mg/kg one of 5 treated chickens died after 8 doses. The survivors all exhibited a weight loss.

At 250 mg/kg all 5 treated chickens died after doses 6 to 9 (Palmer and Radeleff, 1969).

Metabolism

In a study on the metabolic fate of urea herbicides, rats were each fed 4.8 g of monuron in 8 days; the urine was then collected and analyzed. The analyses determined that the majority of the metabolites retained the urea structure and that the chief pathway was a step-by-step demethylation, with a minor step leading to hydroxylation of the benzene nucleus. Monuron and its corresponding dichlorinated analog were the only urea herbicides of those studied in which a total demethylation occurred without simultaneous hydroxylation (Ernst, 1969). The metabolic pathways proposed for monuron were as follows:



Source: Adapted from Ernst (1969).

Determinations of quantitative proportions indicated that the metabolites were distributed so that about 15% excretion was in the form of (II) N-(4-chlorophenyl) urea, about 7% excretion as (III) N-(2-hydroxy-4-chlorophenyl)-urea, and about 2.5% as (IV) N-(3-hydroxy-4-chlorophenyl)-urea.

The enzyme systems responsible for the stepwise demethylation of monuron in rats have not been identified. However, Geissbuhler and Voss (1971) reported that the plant enzyme system involved in N-demethylation is a mixed-function oxidase that is located in the microsomal fraction of plant extracts and which requires molecular oxygen and either NADPH or NADH as cofactors. The authors also concluded that the pathways of transformations of urea herbicides in plants, animals, and soils are so similar as to make a separate discussion of each process unnecessary.

From the results of their studies, Geissbuhler and Voss (1971) concluded that, in animals and in plants, degradation of urea herbicides to the corresponding anilines does not represent a major pathway of transformation for the urea herbicides. From their survey of the literature, they also concluded that the formation of azobenzenes from metabolically-formed anilines does not represent significant terminal residues of urea herbicides.

Excretion - Geissbuhler and Voss (1971) suggested that hydroxylated animal metabolites of urea herbicides could be eliminated mainly in the urine as glucuronides or ester sulfates. Formation of these conjugates lead to very water-soluble compounds. It must be emphasized, however, that the chemical structure of these conjugates has not been verified. The authors believed that the conjugates were β-D-glucoside compounds.

Enzyme Induction - Monuron and other urea herbicides have been found to be inducers of hepatic microsomal enzyme syntheses (Kinoshita and DuBoise, 1970).

Weanling and adult female rats were fed monuron for 1 week at 1,000 ppm, and then the changes in enzymatic activities of O-demethylase, N-demethylase and the hepatic detoxification system were determined. The results of these analyses are shown in Table 3. O-demethylase appeared to be induced to high activity from the feeding of monuron although activity of the hepatic detoxification system and N-demethylase were not increased significantly.

Table 3. INDUCTION OF HEPATIC MICROSOMAL ENZYME ACTIVITY OF RATS

Test group	Days fed at 1,000 ppm	Hepatic detoxification system[a]	O-Demethylase[a]	N-Demethylase[b]
Controls: weanling	7	3.5 ± 0.14	6.6 ± 0.19	3.2 ± 0.23
adult	7	2.8 ± 0.07	5.8 ± 0.22	3.1 ± 0.16
Monuron: weanling	7	3.9 ± 0.32	8.7 ± 0.34[c]	3.0 ± 0.26
adult	7	2.8 ± 0.10	6.7 ± 0.49	3.1 ± 0.35

[a] μg p-Nitrophenol per 50 mg liver per hr.
[b] μg 4-Aminoantipyrine per 100 mg liver per 1/2 hr.
[c] Significantly different from controls ($p < 0.05$).
Source: Adapted from Kinoshita and DuBois (1970).

Monuron was also studied in relation to its effect on enzymes that regulate glycolysis in the liver (Rubenchik, 1970). Enzymatic activity was depressed in liver homogenates from rats fed monuron for 10 weeks when compared to that of rats fed regular diets. However, after 18 weeks of feeding, the activity of the glycolytic systems of monuron-treated animals was increased to levels higher (18.8 versus 10.7 mg lactic acid/g protein) than that of the controls.

Phosphofructokinase (PFK) activity in the livers of rats fed monuron (450 mg/kg) for 10 days was also depressed below control values. As with total glycolysis at 18 weeks, the activity of PFK was higher in monuron-treated rats than it was in controls. Hexokinase activity did not appear to change because of monuron treatment. Known carcinogens and monuron were shown to have produced similar changes in the profile of glycolysis activity in the liver, although tumors were found in the livers of the carcinogen-treated animals, but not in the livers of monuron-treated ones.

Effect on Reproduction

A 3-generation reproductive study was carried out with male and female Rochester strain rats (Sherman and Culic 1971). The animals were fed 0, 125, and 2,500 ppm AI in the diet for 3 generations. Two litters of offspring were produced per generation. At the lower feeding level, no clinical signs of toxicity or deviations from normal reproduction and lactation were observed. At the 2,500 ppm feeding level, the average size of 6 litters was slightly lower than the control group and the 125-ppm group.

Ten male and 10 female weanling rats from each group of $F3_b$ generation were sacrificed. The following tissues were evaluated histologically: lung, trachea, liver, kidney, spleen, thymus, testes, ovary, epididymis, uterus, skeletal muscle, stomach, duodenum, colon, heart, brain, adrenals, eye, and bone marrow. No pathological changes were observed which could be attributable to the test material.

Teratogenic Effects

In a teratogenic screening study, monuron caused no significant increases of anomalies in 3 strains of mice at 215 mg/kg (U.S. Department of Health, Education, and Welfare, 1969).

Oncogenesis

Experiments were conducted on 100 random-bred male white rats, 50 random-bred white mice, and 45 mixed sex, C57BL black mice (low cancer incidence). The rats were fed for 18 months on a diet containing 450 mg/kg monuron (0.12 LD_{50}). Mice received monuron orally in milk at the rate of 6 mg/week, as a single dose, for a period of 15 weeks. The observation period was 27 months for rats and 13 months for mice. All animals which died during the experiment were subjected to necropsy, and tissues from each were evaluated histologically. Animals surviving the experimental period were likewise sacrificed and subjected to necropsy and histological examination (Rubenchik et al., 1970).

The incidence of occurrence and time of appearance of tumors is shown in Table 4. The types of tumors found and time of detection are given in Table 5. Of the rats fed monuron, 18 were sacrificed early in the experiment when the tumor incidence was low. Of the 32 remaining animals, tumors occurred in 15 (46.5%). No tumors were found in the 30 control rats sacrificed at comparable time periods.

Table 4. SUMMARY OF THE ACTION OF MONURON ON EXPERIMENTAL ANIMALS

Animal species	Time of detection of first tumor (weeks)	Animals alive up to detection of first tumor	Animals with tumors	Animals with tumors of different localization occurring at the same time
I Rats	18	32	15	8
II Mice, random-bred	16	23	13	4
III Mice, C57BL strain	4	26	7	1

Source: Adapted from Rubenchik,et al. (1970).

Malignant and benign tumors were found in 56.5% of the random-bred mice and in 26.9% of the C57BL strain. In the controls only 1 tumor occurred (3.9%) in the C57BL strain mouse.

In a study of herbicide metabolism, monuron was fed to rats for 18 weeks at 450 mg/kg without producing tumors in the liver. During the same period, known carcinogens produced liver tumors in all rats tested (Rubenchik 1970).

Monuron was one of 130 compounds evaluated for tumorigenicity by Innes et al. (1969). Male and female mice of 2 hybrid strains (C57BL/6 x C3H/Anf and C57BL/6 x AKR) were given maximal tolerated doses (215 mg/kg) daily by stomach intubation starting at 7 days and continuing until weaning at 4 weeks of age. Following weaning, the same daily dose was administered in the diet until necropsy at 18 months of age. A total of 72 animals were fed throughout the experimental period (18 of each sex for both strains). At necropsy the mice fed monuron had elevated tumor incidence. The range, however, was uncertain and not significant enough to definitely place the compound in the tumorigenic category. It was recommended that the compound be further evaluated.

Table 5. RESULTS OF THE ACTION OF MONURON ON EXPERIMENTAL ANIMALS

	Stomach		Intestine		Liver		Lung		Testis	Kidney
Animal Species	Adenoma Malignant	Scirrhus	Lymphoma	Cytoblastoma	Hepatoma Benign	Hepatocellular Cancer	Cancer Alveolocellular	Cancer Microcellular	Seminoma	Cancer
Rats										
Number of tumors	1	1b/	-	1	1	2	2	4	2	-
Time in weeks	84	83	-	94	72	108, 118	84, 104	18, 100, 102, 118	68, 72	-
Random-Bred Mice										
Number of tumors	1	-	-	-	4	4	2	-	-	2
Time in weeks	17	-	-	-	12, 17,a/ 28	17,b/ 69	16, 30	-	-	17, 104
Mice, C57BL										
Number of tumors	-	-	1	-	2	2	1	-	-	1
Time in weeks	-	-	64	-	4, 14	8, 20	90	-	-	69

a/ Several tumors detected at the same time.
b/ With metastases in the liver.

Adapted from Rubenchik, op. cit. (1970).

Table 6. OBSERVATIONS ON THE TUMORIGENICITY OF MONURON TO RATS AND DOGS

Animal	Strain or type	Sex	Dose	Treated Animals with tumors significantly higher than controls	Survival
2 dogs	Beagle	1 M, 1 F	2.5 mg/kg body weight in food for 1 year	0	Killed at termination of experiment
2 dogs	Beagle	1 M, 1 F	12.5 mg/kg body weight in food for 1 year	0	Killed at termination of experiment
2 dogs	Beagle	1 M, 1 F	25 mg/kg body weight in food for 1 year	0	Killed at termination of experiment
60 rats	Rochester	30 M, 30 F	0.0025% in basal and meat diet for 2 years	0	70 to 90% died by end of second year
60 rats	Rochester	30 M, 30 F	0.025% in basal and meat diet for 2 years	0	70 to 90% died by end of second year
60 rats	Rochester	30 M, 30 F	0.25% in basal and meat diet for 2 years	0	70 to 90% died by end of second year
60 rats	Rochester	30 M, 30 F	Control		70 to 90% died by end of second year

Source: Adapted from Hodge et al. (1958).

Table 6 depicts data for chronic feeding studies performed on dogs and rats (Hodge, et al. 1958). Dogs were given daily oral doses of 2.5, 12.5, and 25 mg/kg body weight monuron in food for 1 yr. Rats were fed 0.0025, 0.025, and 0.25% monuron in the diet for a 2-yr period. The incidence of tumors was observed to be no higher in the experimental groups than in the control groups.

Monuron is currently undergoing chronic testing under the auspices of the National Cancer Institute (at Frederick Cancer Research Center). Both male and female rats and mice are being fed diets containing monuron at the maximum tolerated dose and one-half the maximum tolerated dose.

Mutagenic Effects

Monuron (no precise concentrations given) did not induce point mutations when evaluated with histidine dependent mutants of *Salmonella typhimurium* (Anderson et al., 1972). The assays were conducted without exposure to metabolic activation agents.

Morphological and somatic chromosomal aberrations induced by pesticides in barley (*Hordeum vulgare*) were studied. Barley seeds were exposed to monuron and to a number of other pesticides at a concentration of 1,000 ppm for 12 hr. The mutation rate obtained by these treatments was compared to untreated controls, and to the effects of x-ray radiation at 5,500 roentgens. "Relative efficiency" ratings were assigned to each treatment on a scale from 1 (control) to 32 (mutation rate produced by the x-ray treatment). On this scale monuron evidenced a "relative efficiency" of 10 (U.S. Department of Health, Education, and Welfare, 1969).

Effects on Humans

Data from the EPA Pesticide Episode Review System (PERS) shows a total of 5 episodes involving monuron and formulations containing monuron. The system evaluates episodes involving humans, animals, plants exposure and area contamination. Cause-effect relationships were not established for those incidences involving monuron and combinations with monuron. Two incidences which involved human exposure reported contact dermatitis and itching.

References

Anderson, K. J., E. G. Leighty, and M. T. Takabashi, "Evaluation of Herbicides for Possible Mutagenic Properties." J. Agr. Food Chem., 20(3):649-656 (1972).

Boyd, E. M., and I. Dobos, "Acute Oral Toxicity of Monuron in Albino Rats Fed from Weaning on Different Diets," J. Agr. Food Chem., 17:1213-1216 (1969).

E. I. Du Pont de Nemours and Company, Report on Monuron, EPA Pesticide Petition No. 17 (1952).

Ernst, W., "Metabolism of Substituted Dinitrophenols and Ureas in Mammals and Methods for the Isolation and Identification of Metabolites," J. S. African Chem. Inst., 22:579-588 (1969).

Geissbuhler, H., and G. Voss, "Metabolism of Substituted Urea Herbicides," contained in A. S. Tahori (ed.), Pesticide Terminal Residues: Invited Papers from the International Symposium on Pesticide Terminal Residues, Held at Tel Aviv, Israel, February 17-19, 1971, Butterworth and Company, London (1971).

Hodge, H. C., E. A. Maynard, W. L. Downs, and R. D. Coye, "Chronic Toxicity of 3-(p-Chlorophenyl)-1,1-Dimethyl Urea (Monuron)," A.M.A. Arch. Ind. Health, 17:45-47 (1958).

Hodge, H. C., E. A. Maynard, W. L. Downs, and R. D. Coye, Report on Monuron, EPA Pesticide Petition No. 17, Vol. I (1957).

Innes, J. R. M., B. M. Ulland, M. G. Valerio, L. Petrucelli, L. Fishbein, E. R. Hart, A. J. Pallotta, R. R. Bates, H. L. Falk, J. J. Gart, M. Klein, I. Mitchell, and J. Peters, "Bioassay of Pesticides and Industrial Chemicals for Tumorigenicity in Mice: A Preliminary Note," J. Nat. Cancer Inst., 42: 1101-1114 (1969).

Kay, J. H., Report on Monuron, EPA Pesticide Petition No. 17, Industrial Bio-Test Laboratories report for National Aluminate Corporation (1957).

Kinoshita, F. K. and K. P. DuBois, "Induction of Hepatic Microsomal Enzymes by Herban, Diuron, and Other Substituted Urea Herbicides," Toxicol. Appl. Pharmacol., 17:406-417 (1970).

Palmer, J. S., and R. D. Radeleff, "The Toxicity of Some Organic Herbicides to Cattle, Sheep, and Chickens," U.S. Department of Agriculture Research Report No. 106 (1969).

Rubenchik, B. L., "Effect of Administration of Hepatocarcinogens and the Herbicide Monuron on Intensity of Glycolysis and Activity of Its Regulating Enzymes in Rat Liver Hyalplasm," Byull. Eksp. Biol. Med., 69:61-63 (1970).

Rubenchik, B. L., N. E. Botsman, and G. P. Gorban, "The Carcinogenic Action of the Herbicide Monuron," Voprosy Onkologii, 16(10)51-53 (1970).

Sherman, H., and R. Culik, Report on Monuron, Haskell Laboratory Report No. 300-17, EPA Pesticide Petition No. 17, Vol. I (1971).

U.S. Department of Health, Education, and Welfare, Report of the Secretary's Commission on Pesticides and Their Relationship to Environmental Health (1969).

Zapp, J. A., Jr., Report on Monuron, EPA Pesticide Petition No. 17, Vol. II (1955).

PART II. INITIAL SCIENTIFIC REVIEW

SUBPART C. FATE AND SIGNIFICANCE IN THE ENVIRONMENT

CONTENTS

Page

Effects on Aquatic Species 52

  Fish. 52

    Laboratory Studies 52
    Special Laboratory Studies 52
    Field Studies. 52

  Lower Aquatic Organisms 55

    Laboratory Studies on Animals. 55
    Field Studies. 59

Effects on Wildlife. 60

  Laboratory Studies. 60

Effects on Beneficial Insects. 61

Synergism of Insecticides with Monuron 61

Interactions with Lower Terrestrial Organisms. 61

  Microflora. 61
  Microfauna. 66

Residues in Soil 67

  Laboratory Studies. 67
  Field and Greenhouse Studies. 71

Residues in Water. 77

Residues in Air. 79

Residues in Nontarget Plants 79

Bioaccumulation, Biomagnification and Environmental
  Transport Mechanisms 80

References 82

Preceding page blank

This section contains data on the environmental effects of monuron, including effects on aquatic species, wildlife and beneficial insects, interactions with lower terrestrial organisms and effects on residues in soil, water and air. The section summarizes rather than interprets data reviewed.

Effects on Aquatic Species

Fish -

Laboratory Studies - Available data on the acute toxicity of monuron to fish is summarized in Table 7. The effect of various formulations for several fish species is shown in Table 8. The data indicates that a combination of monuron and trichloroacetic acid (TCA), is more toxic to fish than monuron alone (Walker, 1965).

Goldfish (*Carassius auratus*) have been reported to survive a 5-day exposure to 59.5 ppm monuron, and a 35-day exposure to 14.9 ppm (Lawrence, 1962).

The 3-hr approximate safe upper limit for initial concentration of monuron applied to fish-bearing waters is reported to be 20 ppm (Edson, 1958).

Special Laboratory Studies - Komarovsky and Popovich (1971) have reported the chronic effects of monuron to *Leuciscus idus* (golden orfe) and *Rutilus rutilus*. "Monurox" (10% monuron, 10% TCA, [TCA alone is more toxic to fish than monuron alone] 80% inert ingredients) applied at the rate of 40 kg/ha active ingredient (AI) (20 mg/l AI) to artificial ponds caused decreased hemoglobin, erythrocyte and hematocrit counts in fish for up to 75 days after treatment when compared to fish in control ponds. There was also a 46% loss of fish over the test period.

Field Studies - Springer (1957) studied the toxicity of monuron to small golden shiners (*Notemigonus crysoleucas*) in ponds. He reports that "some mortality" (not quantified) occurred at a dosage of 20 ppm of monuron.

Bond et al. (1959) reported that the treatment of ponds with monuron at 5 and 10 ppm caused no mortality either to Coho salmon (*Oncorhynchus kisutch*), frogs or tadpoles.

Table 7. ACUTE TOXICITY OF MONURON TO FISH

Species	Purity (%)	Exposure time (hr)	Temperature (°C)	Toxicity calculation	Toxicity value (ppm)	References
Striped mullet (*Mugil cephalus*)	-	48	-	LC_{50}	16.3*	a/
White mullet (*Mugil curema*)	-	24 48	28	TL_m+ TL_m	20.0 16.3	b/
Rainbow trout (*Salmo gairdneri*)	80	24 48	28	LC_{50} LC_{50}	180 100	c/
Largemouth bass (*Micropterus salmoides*)	++	48	20	10% mortality	230	d/
Coho salmon (*Oncorhynchus kisutch*)	++	24 48	20 20	TL_m TL_m	115 110	d/
Carp (*Cyprinus carpio*)	-	48	-	TL_m	>10	e/

---

* Standing water test.
+ Median tolerance limit.
++ Concentrations are given in terms of active ingredient.
a/ Butler (1965).
b/ U.S. Fish and Wildlife Service (1963).
c/ Alabaster (1969).
d/ Bond (1959).
e/ Nishiuchi (1974).

Table 8. EFFECT OF FORMULATION ON THE ACUTE TOXICITY OF MONURON TO FISH

		Size	Concentration (pp		
Formulation	Fish species	(inc.)	EC$_{10}$a/	EC$_{50}$a/	EC$_{90}$a/
Monuron 80% WP	Bluegill (*Lepomis macrochirus*)	4-5	20.0	33.0	55.0
Monuron 80% WP	Brown bullhead (*Ictalurus nebulosis*)	3-4	40.0	57.0	80.0
Monuron 25% pellet	Bluegill (*Lepomis macrochirus*)	4-5	27.0	40.0	60.0
Monuron 25% pellet	Redear sunfish (*Lepomis microlophus*)	4-5	31.5	47.0	60.0
Monuron-borate 4% granular	Bluegill (*Lepomis macrochirus*)	4-5	17.5	26.0	40.0
Monuron-TCA 3 lb/gal	Bluegill (*Lepomis macrochirus*)	2-3	0.7	1.5	3.0
Monuron-TCA 3 lb/gal	Bluegill (*Lepomis macrochirus*)	4-5	1.0	1.8	3.1
Monuron-TCA 3 lb/gal	Largemouth bass (*Micropterus salmoides*)	4	1.1	2.7	6.0
Monuron-TCA 11% granular	Bluegill (*Lepomis macrochirus*)	2-3	2.0	3.8	7.0
Monuron-TCA 22% granular	Bluegill (*Lepomis macrochirus*)	4-5	2.3	4.8	10.0
Monuron-TCA technical	Pumpkinseed (*Lepomis gibbosus*)	2-3	1.7	3.3	6.0
Monuron-TCA technical	Bluegill (*Lepomis macrochirus*)	2-3	2.0	4.5	9.6
Monuron-TCA technical	Bluegill (*Lepomis macrochirus*)	4-5	2.4	5.0	10.0
Monuron-TCA technical	Redear sunfish (*Lepomis microlophus*)	4-5	3.1	5.4	9.0
Monuron-TCA technical	Largemouth bass (*Micropterus salmoides*	4	3.0	4.8	8.0

---

a/ EC$_{10}$, EC$_{50}$, EC$_{90}$ = Effective concentration in parts per million which produced 10%, 50%, and 90% mortality, respectively, in a 96-hr exposure period.

Source: Adapted from Walker (1965).

When 2 ppm monuron (as 80% AI commercial wettable powder) was sprayed on a pond for algae control, smallmouth bass appeared to be agitated but no dead fish were found (Maloney, 1958). The fish returned to normal the following day. It was concluded by the investigator that the agitation was due to reduction of dissolved oxygen by the dead or dying algae and not due to agitation by monuron per se.

Hiltibran (1967) undertook studies to determine the toxicity of several herbicides, including monuron to fish embryos and fry. In a preliminary experiment in which monuron was not included, it was determined that the exposure of fertilized eggs of the stoneroller (Campostoma anomalum) to concentrations of different herbicides ranging from 5 to 50 ppm did not prevent the development of fry. Because of the difficulties involved in using fertilized fish eggs in toxicity experiments, only fry were used in subsequent tests in which monuron was included. Fish fry appeared to be more susceptible to the toxic action of the herbicides than fertilized fish eggs. Monuron was used in the form of a granular monuron-TCA formulation (concentration not specified) at 22 to 25°C. Twenty ppm was the highest concentration of monuron which did not cause death of small bluegills (Lepomis macrochirus) during a 12-day exposure period. At 10 ppm, monuron did not cause any loss of fry of bluegill or lake chubsucker (Erimyzon sucetta), exposed for 8 days. At the same rate, green sunfish (Lepomis cyanellus) fry survived no longer than 5 days, and smallmouth bass (Micropterus dolomieu) fry survived for only 4 days.

Lower Aquatic Organisms -

Laboratory Studies on Animals - The toxicity of monuron to estuarine animals was studied by Butler (1963). Adult white shrimp (Penaeus setiferus) were exposed to monuron for 24 and 48 hr at an average temperature of 24°C, and 30 parts per thousand salinity. At the highest rate tested, 1.0 mg/l, monuron had no effect (death, paralysis, or loss of equilibrium) on the test animals. The Eastern Oyster (Crassostrea virginica) was exposed to monuron at an average temperature of 22°C, and a salinity of 25%. At a concentration of 2.0 mg/l, there was a 12% decrease in oyster shell growth after an exposure of 96 hr. In these tests, monuron was considerably less toxic to the test organisms than most other pesticides tested under similar experimental conditions.

Davis and Hidu (1969) studied the acute and subacute toxic effects of pesticides and solvents on the American (or Eastern) oyster and the hard clam (Mercenaria mercenaria). The temperature was 24°C and the pesticide medium was removed and renewed every second day. Monuron in water solution had 48 hr. and 12 day TL_m's of > 5.00 ppm both for the oyster and hard clam. The authors reported that the TL_m values listed are of significance for rough comparisons of toxicity only because some compounds drastically reduce the rate of larvae growth at concentrations too low to cause appreciable mortality. Some concentrations may kill embryos at lower levels than are required to affect growth or survival of larvae. Davis and Hidu also listed effects on development of eggs and survival and growth of clam larvae (expressed as percentages of control) at 4 concentrations for monuron:

Concentration (ppm)	Eggs developing (%)	Larval survival (%)	Larval growth (%)
0.25	93	120	114
0.50	99	122	109
1.00	91	128	86
5.00	92	111	93

Springer (1957) reported that at a dosage of 20 ppm applied to water, monuron did not cause mortality in amphipods or isopods.

Crosby and Tucker (1966) determined the toxicity (median immobilization concentration) of a number of herbicides, including monuron, to Daphnia magna. The tests were performed at 21.1°C in boiled deepwell tap water to which a nonionic surfactant (Tween® 20) was added at a concentration of 1 ppm. Monuron caused immobilization of 50% of the test animals (IC_{50}) at a concentration of 106 ppm. Monuron was 1 of 5 herbicides whose IC_{50} concentrations were above 100 ppm.

Nishiuchi (1974) reported the TL_m value (3 hr) for Daphnia pulex as > 0.5 ppm.

Walker (1965) conducted extensive studies on monuron and several other substituted phenyl-urea herbicides to determine their usefulness as aquatic herbicides. Field tests followed laboratory bioassay tests for fish toxicity (reviewed in the preceding subsection) which showed that monuron was less toxic to fish than other herbicides of this type. At a dosage rate of 1 to 2 ppm, monuron reduced the total numbers and the total weight in grams of bottom-dwelling fish-food organisms 3 months after treatment. Primarily, weed-clinging species of Gastropoda, Odonata and Trichoptera were eliminated, along with Ephemeroptera (mayfly nymphs) which are quite sensitive to pollution. The total number of bottom-dwelling fish-food organisms per square foot was reduced from 153 in an untreated area to 95 in the monuron-treated area, and the total weight of such organisms was reduced from 1.87 g (untreated) to 1.53 g in the monuron-treated areas. These counts were taken 3 months after monuron application. Walker concludes that monuron showed potential for the control of aquatic plants at rates of 1 to 5 ppm, or 20 to 50 lb/acre. According to the author, monuron and the related substituted urea herbicides tested "did not appear to seriously reduce fish-food organisms, and no fish mortalities were observed under field conditions at concentrations up to 10 ppm of monuron."

Shcherban (1971) studied the effects of monuron on the productivity of several species of planktonic Cladocera. At the rate of 2 mg/l monuron significantly increased the number of days between births in Daphnia magna, Moina rectirostris and Scapholeberis macronata, and also significantly increased the time necessary for offspring to reach fertility in M. rectirostris and S. macronata. Monuron significantly decreased the average lifespan of Ceriodaphnia quadrangula, the total number of births in a lifespan in all 4 species, the number of young produced per birth in M. rectirostris, C. quadrangula and in S. macronata, and the potential productivity of D. magna, M. rectirostris, and S. macronata.

Pidgaiko (1971) investigated the effect of monuron and 2 related urea herbicides on the rate of reproduction of zooplankton species by exposing them to the pesticides in aquarium water and determining the offspring which developed between 20 to 75 days after treatment. Monuron and the related herbicides greatly suppressed the rate of reproduction, especially of *Scapholeberis macronata*.

Imam and Ghabbour (1966) studied the effects of 5 herbicides on the aquatic oligochaete *Branchiura sowerbyi* (Tubificidae), an indirect pest in rice nursery beds. *B. sowerbyi* survived for 2 weeks in monuron (pond) at a concentration of 100 ppm. They survived for only 4 days at 500 ppm and one-half day at 1000 ppm.

Laboratory Studies on Plants - Ukeles (1962) studied the toxicity of monuron and several related phenylurea herbicides to pure cultures of marine plankton, including *Protococcus* sp., *Chlorella* sp., *Dunaliella euchlora*, *Phaeodactylum tricornutum*, and *Monochrysis lutheri*. Monuron completely inhibited the growth of these organisms at 0.02 ppm. Only one pesticide tested in this series was more toxic than monuron to most of the marine phytoplankton species tested. Fifteen other pesticides studied under the same conditions were considerably less toxic to these organisms than monuron.

Butler (1965) investigated the effects of a large number of pesticides on estuarine phytoplankton. The organisms (described only as "phytoplankton," not individually identified) were exposed to the pesticides at a standard concentration of 1.0 ppm for 4 hr. Under these conditions, monuron reduced carbon fixation by 94%; it was the most toxic among 26 herbicides tested. Five other herbicides reduced carbon fixation by more than 75%, while 9 herbicides caused no decrease in carbon fixation.

Walsh (1972a) studied the effects of a number of different herbicides and herbicidal formulations on photosynthesis and growth of 4 species of marine unicellular algae, including the chlorophytes *Chlorococcum* species, *Dunaliella tertiolecta*, the chrysophytes *Isochrysis galbana*, and *Phaeodactylum tricornutum*. The organisms were grown and tested in a medium of artificial seawater at 20°C supplemented with trace elements and vitamins. The salinity of the medium was 30 parts per thousand, and the pH ranged from 7.9 to 8.1. Monuron was tested only in the form of the technical acid. The concentrations of monuron that decreased oxygen evolution of the study organisms by 50% (EC_{50}) and 100% (EC_{100}), and the concentrations that decreased growth by 50 and 100%, respectively, were as follows:

	Chlorococcum	*Dunaliella*	*Isochrysis*	*Phaeodactylum*
Oxygen evolution				
EC_{50}, ppm	0.10	0.09	0.10	0.09
EC_{100}, ppm	0.20	0.16	0.17	0.17
Growth reduction				
EC_{50}, ppm	0.10	0.15	0.13	0.10
EC_{100}, ppm	0.25	0.25	0.28	0.25

In general, triazine herbicides investigated under the same conditions were more toxic or as toxic as substituted urea herbicides.

Walsh and Grow (1971) investigated the effects of different salinities on the inhibition of the growth of 6 genera of marine unicellular algae by 4 urea herbicides, including monuron. Test organisms included the same 4 species studied by Walsh (1972b), and 2 additional chlorophytes, including Dicrateria inornata and Nannochloris species. When Chlorococcum species were exposed to monuron at concentrations of 10, 50, and 100 ppb at salinities of 5, 10, 20, and 30 parts per thousand, it was found that salinity had no effect on the inhibition of growth by the herbicide. The growth of Chlorococcum was inhibited by 10 to 12% at 10 ppb of monuron; 22 to 25% at 50 ppb; and 52 to 62% at 100 ppb. Growth inhibition data for all other species of algae were similar. Again, monuron was less toxic to the test organisms than some other herbicides of this type. The herbicides did not affect total protein, total chlorophyll, or carotenoid contents of the algae at any salinity. They did, however, produce changes in the carbohydrate content in relation to salinity; increasing salinity produced increasing depression of carbohydrate content. Chlorococcum, the most susceptible species, lost 65.6% of its total carbohydrate when treated with monuron at 100 ppb at 30 parts per thousand salinity or with concentrations of other urea herbicides that inhibited growth by 50 to 75%.

Braginskii et al. (1969) investigated more than 400 chemicals for their suitability to control 4 species of algae, including Microcystis aeruginosa, M. pulveraea, Anabaena hassalii, and A. variabilis. While most of the substances were inactive, monuron and several other herbicides were active at 0.5 to 2.0 mg/l. None of the chemicals tested were 100% effective, and most of the herbicides did not act upon blue-green algae.

Hoffman (1971) and Sweetser and Todd (1961) demonstrated that monuron is toxic to algae (including Chlorella sp. and Euglena sp.) in the light, but not in the dark, regardless of whether or not the growth medium contains energy sources.

Sweetser (1963) in further studies on the mechanism of action, found that the addition of monuron (no rate given) to a culture of Chlorella in light resulted in the immediate inhibition of photosynthesis as determined by the CO_2 fixation rate. When FMN (riboflavin-5'-phosphate) was added to the culture (rate not given), photosynthesis returned to the pre-inhibition level within a few minutes. When FMN was incubated with monuron (rates not given) in flat-sided flasks exposed to white light (from a 150 W reflector spot lamp for 5 hr, while heat from the lamp was filtered out), the reaction mixture no longer inhibited CO_2 fixation by Chlorella. The author concluded from these observations that FMN photochemically inactivated monuron both in the presence and absence of algae. A high molecular weight compound which was no longer antiphotosynthetic was isolated from the monuron-FMN reaction mixtures. The isolated reaction product had a meling point of around 300°C (with decomposition), and a molecular weight of 1,250 to 1,300. Nuclear Magnetic

Resonance analysis showed only phenyl and CH_3 protons with no indication of hydroxy protons. The ratio of phenyl protons to methyl protons was 200:318. Analysis of the reaction product for p-chloroaniline indicated a content of only 3 to 5%, while a monuron control gave the theoretical 64%. On the basis of this analytical data, it was not possible to assign a structure to the monuron-FMN reaction product. The author speculates that several monuron molecules condense to form a major portion of this molecule. The discovery of this photochemical inactivation of monuron by FMN points to the possibility that monuron may inhibit photosynthesis by interacting with FMN or a flavoprotein in the photosynthesis pathway.

Vandermeulen et al. (1972) utilized the properties of monuron and a closely related herbicide as selective photosynthesis inhibitors in a study on algae-invertebrate symbiotic associations. Monuron at 99.35 ppm completely inhibited photosynthesis both in intact branches and in suspensions of isolated zooxanthellae from the reef-building coral Pocillopora damicornis, as well as in 8 other marine coelenterates symbiotic with zooxanthellae, and in 1 marine gastropod symbiotic with functional chloroplasts. The inhibitory effect was totally reversible within 1 to 3 hr after removal of the inhibitor. Monuron did not appear to affect the behavior of the various hosts. Monuron also reversibly inhibited light-enhanced calcification in P. damicornis at 5×10^{-4} M.

Field Studies - A search of the literature and of other data sources failed to produce any reports in English-language primary publications on the effects of monuron on lower aquatic organisms under field conditions. However, one report by Russian authors was found.

Pidgaiko and Shcherban (1970) studied the development of zooplankton and zoobenthos in reservoirs treated with monuron for the control of algae, especially Microcystis aeruginosa and M. pulverea. Monuron was used in the form of a granular formulation (rate of application not specified). During a 2-yr period, the biomass of zooplankton and zoobenthos decreased by 75% as a result of oxygen depletion and direct toxic effects of monuron. The populations of Cladocera and Oligochaeta were suppressed to a greater degree than those of Copepoda and Chironomidae.

The Federal Water Pollution Control Administration (1968) classifies substituted urea compounds in "Pesticide Group B" as to their hazard to marine and estuarine organisms. Pesticides in this category are characterized as "generally not acutely toxic at levels of 1.0 mg/liter or less." It is recommended that an application factor of 1/100 be used and, in the absence of acute toxicity data, that environmental levels of not more than 10 μg/l be permitted. An acute toxicity factor must be established for each chemical in the group to ascertain if it is not more toxic than related compounds. In this system, pesticides are grouped according to their relative toxicity to shrimp, "one of the most sensitive groups of marine organisms."

Effects on Wildlife

Laboratory Studies - Heath et al. (1972) have calculated dietary LC_{50} values for monuron for 4 species of birds. The values were determined by administering monuron in feed to bobwhite quail (*Colinus virginianus*), Japanese quail (*Coturnix coturnix japonica*), ring-necked pheasants (*Phasianus colchicus*), and mallard ducks (*Anas platyrhnchos*). Birds, 2- to 3-weeks old, were fed the treated diets for 5 days followed by a 3-day observation period to detect chemical mortality induced beyond the treatment period. Data from the study is summarized as follows:

Table 9. EFFECTS OF MONURON ON QUAIL, PHEASANT AND MALLARD DUCKS

Species	No. of concentrations tested	Birds per concentration	LC_{50} (ppm in feed)
Bobwhite quail	3	6	> 5,000
Japanese quail	3	14	> 5,000 (21% mortality at 5,000)
Ring-necked pheasant	5	9	4,682 (95% conf. limit 3,902 - 5,746)
Mallard Ducks	3	10	> 5,000 (10% mortality at 5,000)

Longer-term studies have been conducted on bobwhite quail and an unspecified species of pheasant (DeWitt et al. 1963):

Table 10. EFFECT OF MONURON ON BOBWHITE QUAIL AND PHEASANT

Species	Monuron in diet (ppm)	Number of birds	Length of test period (days)	Percentage mortality at end of: 10 days	30 days	Test period	Time to 50% mortality (days)
Bobwhite quail (1 to 2 days of age at start of test)	5,000	21	14	86	-	100	4
	2,500	21	14	57	-	100	5
Ring-necked pheasant (adult)	5,000	10	87	0	50	80	24

Effects on Beneficial Insects

Atkins et al. (1973) summarized the results of toxicity tests of a large number of pesticides and other agricultural chemicals to honeybees (Aplis mellifera) in a laboratory procedure which primarily measures a pesticide's contact effect. Pesticides are applied in dust form to groups of 25 bees per test level, 3 replicates for each of 3 colonies, for a total of 9 replicates per test level. The procedure permits determination of an LD_{50} value for each pesticide in micrograms of chemical per bee.

Honeybees were exposed to monuron for 48 hr at 80°F (26.7°C) and 65% relative humidity. Under these test conditions, the LD_{50} of monuron was 110 µg/bee, which according to Atkins et al. would equal a rate of 110 lb/acre and places it in Group II, "moderately toxic to honeybees."

In their test procedure, Atkins et al. (1973) also determined the slopes of the dosage-mortality curves and recorded a "slope value" in terms of probit units for each pesticide tested. Pesticides with a slope value of 4 probits or higher can often be made safer to honeybees by lowering the dosage only slightly. Conversely, by increasing the dosage only slightly, such pesticides can become highly hazardous to bees. Monuron rated a very low "slope value" of 0.78, indicating that very large changes in dosage rate would be required to change its bee toxicity. This data indicates that monuron would be moderately toxic to honeybees if rates exceeded recommended application rates.

Synergism of Insecticides with Monuron

Lichtenstein et al. (1973) have studied the synergistic effect of 4 herbicides, including monuron, on the toxicity of 12 insecticides. Monuron was tested against only 2 insecticides, an organophosphate and a chlorinated hydrocarbon. Monuron had a statistically significant synergistic effect on the toxicity of the organophosphate to the fruit fly, Drosophila melanogaster, and to the mosquito, Ades aegypti. In tests using the housefly, Musca domestica, monuron had a significant synergistic effect on the toxicity of the 2 insecticides.

Interactions with Lower Terrestrial Organisms

Microflora -

Fungi and Actinomycetes - Murray et al. (1969) studied the degradation of monuron and 4 other substituted urea herbicides by Aspergillus niger, A. sydowi, and A. tamarii and the effects of urea nitrogen levels of 0, 45, 450 and 900 ppm on this process. The toxicity of monuron to the 3 Aspergillus species was intermediate between 2 other herbicides of this type. Monuron completely inhibited the growth of A. niger at 1,000 ppm, while A. sydowi and A. tamarii made some growth at this concentration. At 10 and 100 ppm of monuron, there was relatively little inhibition of the growth of A. niger as compared to monuron-free cultures. A. sydowi and A. tamarii were less tolerant to these lower levels of monuron than A. niger. The higher nitrogen levels resulted in delayed spore formation and changed the appearance of the mycelial pad.

The degradation of monuron and the other substituted urea herbicides was determined by growing isolates of the 3 fungi on both media containing the herbicides at levels of 0, 5, 10, and 20 ppm. After incubation for 5 days, the dry mycelial pads and the residual media were mixed thoroughly into Eufaula sand (pH 5.7; 90% sand, 7% silt, 3% clay, 0.5% organic matter; exchange capacity 2.7 meq with low levels of available phosphorus and potassium). Three successive plantings of cucumber were grown in 4-in square plastic pots of this treated soil. The same Eufaula sand was also used to determine the phytotoxicity of monuron and the other herbicides as affected by soil organic matter composition. In these tests, 1% by weight of 3 different combinations of organic material were added to the Eufaula sand, representing high carbon-low nitrogen, medium carbon and nitrogen, and low carbon-high nitrogen mixtures.

Monuron was more resistant to decomposition by the 3 Aspergillus species than other herbicides of this type, especially at the 20 ppm level. The cucumber plant yields increased significantly with increased soil organic nitrogen levels without herbicide additions. All rates of monuron depressed the cucumber plant yields. In this test series, monuron again was more resistant to decomposition than the other substituted urea herbicides studied.

Lopez and Kirkwood (1972, 1974) studied the growth patterns of a fungus of the genus Fusarium as affected by different concentrations of monuron and a related herbicide. The fungus and 2 unidentified bacteria were isolated by plating out small samples of a fine sandy loam which had been profused with monuron at a concentration of 500 μg/ml for 2 weeks on Czapek's solution agar. The 3 isolates were tested for their ability to use different concentrations of the herbicides as sources of carbon. In the presence of 1 g/l of yeast extract, the fungus attained optimal growth at 10 and 20 ppm of monuron. Without yeast extract, best growth was observed at 2 ppm of monuron. In the latter test series, the fungus grew better in media containing 2 ppm of monuron than in those containing none, as determined by colony diameter and CO_2 evolution. The authors suggest that the Fusarium species as well as the 2 unidentified isolated bacteria may be able to use monuron as a carbon source.

Lanzilotta and Pramer (1970) isolated an enzyme, identified as acylamidase, from Fusarium solani. The substrate range and affinity of the enzyme, which was found capable of hydrolyzing an acetanilide pesticide, was investigated. It was determined that the acylamidase had a high affinity for acetanilides but was unable to hydrolyze monuron and several other herbicides.

Wallnofer et al. (1973) investigated the interactions between Rhizopus japonicus and 4 phenylurea herbicides, including monuron. The fungus was grown in a synthetic glucose medium on a gyratory shaker under aerobic conditions at a temperature of 30°C, at pH ranging from 6.0 to 7.5. Under these conditions, R. japonicus demethylated monuron into the metabolite 3-(p-chlorophenyl)-1-methylurea. Three related phenylurea herbicides were also dealkylated. The metabolites were identified by nuclear magnetic resonance and mass spectrometric analysis. They were present after incubation for 1 week.

Hachimori et al. (1968) found that monuron and several other related phenylurea herbicides inhibited the respiration of yeast mitochondria, while 2 uracil and 2 triazine herbicides were ineffective.

Based on an extensive review of the literature on interactions between herbicides (and other pesticides) and the microflora, Audus (1970) concluded that most herbicides, including the phenylureas, are without effect on fungal populations at normal field rates. Actinomycetes are, in general, very tolerant to phenylureas and other herbicides.

Audus further reported that the root rot of barley, a seedling disease caused by Helminthosporium sativum, was alleviated by soil applications of monuron (and several other herbicides). The mechanism of this effect was not reported; however, it is believed that the herbicides may have altered the pathogen's infectivity.

The fate of 4-chloroaniline, which is produced from monuron by photodecomposition and through the metabolic process of certain plants (Smith and Sheets, 1967; Swanson and Swanson, 1968), has been studied by Kaufman et al. (1973). The experiment was performed using a laboratory flask, not actual soil; only one microbial species, the fungus Fusarium oxysporum, was used.

Kaufman et al. (1973) determined that the major pathway of Fusarium oxysporum degradation of 4-chloroaniline was oxidation of the aromatic amine group. A secondary pathway was acylation of the aromatic amine group. The degradation scheme proposed by Kaufman et al. (1973) is shown in Figure 4.

Another compound, tentatively identified, but not shown in Figure 4, is 2-chloro-4-nitrophenol. The formation of this compound implies migration of the chlorine substituent. The production of the chloride ion was also detected during the metabolism; Kaufman et al. (1973) note that as much as 98% of the organically bound chloride was liberated after incubation periods of 10 to 12 days. All of the metabolites identified by these authors contained chlorine; however, they detected two phenolic metabolites which were not characterized.

Bacteria - Hill et al. (1955) and Hill and McGahen (1955) demonstrated that soil microorganisms play an important role in the decomposition of monuron and other phenylurea herbicides in soils. By use of the dilution plate technique, they found that monuron applied to agar medium at a concentration of 250 ppm had no adverse effect on soil microbe populations. The authors isolated bacteria species of Pseudomonas, Xanthomonas, Sarcina, and Bacillus, and two fungi, Penicillium and Aspergillus, which utilized monuron as the sole source of carbon. Other soil microorganisms were found which were capable of oxidizing monuron if accessory growth factors found in organic materials, such as yeast extract, are present. Since such growth factors are normally present in the soil organic or mineral matter, the authors conclude that probably both types of organisms are active in the decomposition of monuron under field conditions. The microorganisms studied are commonly found in all agricultural soils.

Wallnofer (1969) studied the decompositon of monuron and several other phenylurea herbicides by *Bacillus sphaericus* isolated from soil previously treated with a methoxy phenylurea herbicide in a basal medium fortified with 3.7 mg of a vitamin mixture per 1,000 ml. Three methoxy phenylurea herbicides were degraded by *B. sphaericus* within 1 week, whereas monuron and several other N-alkyl (as opposed to N-alkoxy)-substituted phenylureas appeared to be resistant to decomposition by *B. sphaericus*. In a series of additional studies, Wallnofer and Bader (1970), and Engelhardt et al. (1971) studied the degradation of urea herbicides by several different strains of *B. sphaericus*, and by cell-free extracts of this organism. An enzyme preparation obtained from a cell-free extract was found to be responsible for the hydrolysis of N'-methoxy phenylurea herbicides. However, as in the studies with whole cells, the N', N'dimethyl phenylurea herbicides, such as monuron, were relatively resistant to decomposition by the cell-free extracts.

Audus (1970) reports that monuron at normal field rates inhibited nitrification (ammonia oxidation) in soil perfusion tests for at least 2 weeks. This inhibition was accompanied by an accumulation of nitrite, suggesting that *Nitrobacter* was more sensitive to monuron than *Nitrosomonas*. These findings agree with earlier reports, including that by Quastel and Scholefield (1953) who described monuron as a powerful inhibitor of soil nitrification. Likewise, Otten et al. (1957) reported that monuron at normal application rates (1 to 5 lb AI/acre) inhibited soil nitrification. However, Hale et al. (1957) reported that at a concentration of 50 ppm, monuron had no noticeable effect upon nitrifying microorganisms.

Audus (1970) reports further that the phenylurea herbicides are without effect except at very high concentrations far in excess of normal field rates, on free-living nitrogen-fixing organisms, based on extensive studies on the growth and metabolism of *Azotobacter* species and a few studies on *Clostridium*. Likewise, phenylurea herbicides did not have any adverse effects at normal field rates on *Rhizobia*, on cellulolytic soil organisms, or on gross bacterial numbers.

Goguadze (1968) studied the effects of herbicides on the development of *Azotobacter* in the western Georgia region of the Soviet Union. Monuron applied as a spray to an alluvial soil at the rate of 7.1 to 8.9 lb/acre (8 to 10 kg/ha) did not affect the development of *Azotobacter* above pH 5, but suppressed it at pH 5. Chuderova and Zubets (1970) likewise reported that the application of monuron (and of more than 20 other herbicides) to sod-podzolic soils during the growing season had no significant effect on the nitrification rate of the soils, nor on the number of nitrifying bacteria. All herbicides were applied at normal field rates recommended by the manufacturers. On the other hand, Babak (1968) reported on laboratory studies which indicated that Azotobacter chroococcum and A. galophilum isolated from various soils were sensitive to monuron and to 11 other herbicides studied.

Shchetinskaya and Bagnyuk (1972) found that monuron at the rate of 5 to 40 mg stimulated the dehydrogenase activity of Pseudomonas fluorescens in the absence of other energy sources, but not when glucose or peptone were present.

Algae - Pantera (1970) studied the effects of monuron and several other urea and triazine herbicides on algae in the soil. Monuron and the other herbicides were applied once a year during a 4-yr period at rates used in field practice, and, in a parallel test series, at rates several times higher. Among the herbicides studied, monuron was most toxic, while ethoxy phenylurea herbicide and the 3 triazine herbicides had only negligible effects on the algae at the high dosage rates.

Pillay and Tchan (1972) developed an algal bioassay method using Chlorella and Chlamydomonas species to study the soil factors affecting the toxicity of herbicides. They found that organic matter adsorbed 18 times the amount of herbicides adsorbed by clay. Among the herbicides studied, phenylureas were more toxic to algae than triazines. Within the phenylurea group, monuron was less toxic to algae than 2 other herbicides.

Unidentified or Mixed Soil Microorganisms - Danuta (1967) studied the effects of monuron and other herbicides on the oxygen uptake of unidentified soil microorganisms, using the Warburg method. The herbicides were used at normal field rates, and the treated soils were incubated in Warburg vessels for 14 or 19 days. Neither monuron nor any of the other herbicides tested had any effects on the oxygen uptake by the soil, or on the number of soil microorganisms as determined by a routine plate method.

McClure (1970) investigated the effects of microbial substrates on the degradation of monuron and other herbicides in soil. Small flats of composted Norfolk dry loam were treated with monuron at the rate of 1.5 lb/acre. Double strength Czapek-Dox broth and Difco nutrient broth (200 ml) were added to some of the flats which were then incubated at 30°C for 7 or 21 days before planting with 5 different test plant species. In a second test series, flats were incubated for longer periods of time, with additional broth treatments given at biweekly intervals. The broth treatments accelerated the degradation of phytotoxic residues of all herbicides studied, including monuron.

Polyvyannyi (1970) applied several herbicides, including monuron at 0.89 and 2.7 lb/acre (1 and 3 kg/ha), to several different soils and studied the effect of these treatments on the concentrations of nitrate, ammonium nitrogen, and the water-soluble organic matter. Observations on untreated controls, freshly treated soil samples, and samples after 3 hr of autoclaving showed that the herbicide treatments and autoclaving produced a similar effect on concentration of nitrogen and water-soluble organic matter. The killing of soil microorganisms liberated their cell constituents into the soil solution. The herbicide treatments had no effects on the concentrations of nitrogen and water-soluble organic matter in previously sterilized soil samples.

Tulabaev (1971) studied the effects of monuron and several other herbicides on the microflora of meadow soil. Monuron applied at the rate of 1.3 lb/acre (1.5 kg/ha) decreased the number of Azotobacter and ammonia-fixing bacteria in the soil. Fungi and cellulose-assimilating bacteria were less affected. In the monuron plots as well as in those treated with the other herbicides, the number of weeds and the consequent loss of nitrogen and phosphorus from the soil were decreased, and the yields of corn and cotton were improved.

Akopyan and Agaronyan (1968) studied the effects of monuron and several other herbicides on the soil microflora in a vineyard in Armenia. Monuron and the other herbicides were applied by soil incorporation at the rate of 7.1 lb/acre (8 kg/ha) prior to weed emergence. Counts of microorganisms in the 0 to 11.8 in (0 to 30 cm) soil layer showed that monuron had only a slight effect on the soil microflora. There were no significant effects on the nitrifying capacity of the soil.

Goguadze (1969) studied the change in the composition of the soil microflora due to the use of herbicides in various stages of grapevine development in alluvial soils. Monuron was applied at the rate of 7.1 lb/acre (8 kg/ha) to the soil, pH 6.0 to 6.5. In the early part of the season, the total quantity of microorganisms in the treated area decreased, but fungi, actinomycetes, and nitrogen-fixing organisms increased. Later in the growing season, several bacterial species increased.

Pantera (1972) investigated the effect of high doses of monuron and several other herbicides on selected groups of soil microorganisms. Among 4 herbicides studied in a 5-yr field experiment, monuron inhibited microbial growth most strongly.

Microfauna - Fox (1964) studied the effects of monuron and 4 other herbicides on the numbers of soil invertegrates in grassland soil. Monuron was applied at the rate of 10 lb/acre. Fourteen months after this application, the following significant reductions were reported: wireworms (Elateridae) 87.5%, millipedes (Diplopoda), 57%, earthworms (Lumbricidae), 43%, springtails (Collembola), 64%, and mites (Acarina), 76% in the monuron-treated plots. Monuron and several other herbicides almost eliminated grasses, but increased stands of wild carrot (Daucus carota) and sheep sorrel (Rumex acetosella). The author suggested that the major effects of the herbicides on the soil microfauna may be indirect and attributable to changes in the floristic composition of the treated grassland, although a combination of these indirect effects and direct actions on the soil invertebrates cannot be excluded.

Edwards (1970) reviewed the effects of herbicides on the soil. He reported that at the rate of 17.8 lb/acre (20 kg/ha) monuron decreased the number of millipedes and springtails in the soil. On the basis of the findings by Fox (1964), Wojewodin (1958), and observations of his own, Edwards concluded that monuron and several other herbicides may affect the numbers of soil invertebrates but, he pointed out, the direct effects of these herbicides on the soil microfauna were never severe with monuron, and occurring only after very large doses were applied to the soil.

Martin and Wiggans (1959) studied the toxicity of monuron to earthworms. Test animals were emersed in monuron solutions for 2 hr. There was 10% mortality of earthworms at a monuron concentration of 1 ppm, 100% mortality at 100 ppm.

Van der Drift (1970) reviewed the effects of pesticides on the soil fauna. He concluded: "Herbicides and fungicides, which are designed to control weeds and fungal parasites, generally affect the soil fauna only to a limited degree."

Residues in Soil

Laboratory Studies - Harris (1966) studied the adsorption, movement, and phytotoxicity of monuron and several triazine herbicides in 4 different Maryland soils (Lakeland sandy loam, Wehadkee silt loam, Chillum silt loam, and Hagerstown silty clay loam). All herbicides studied were least adsorbed on the Lakeland sandy loam, and most highly adsorbed on either the Chillum silt loam, or the Hagerstown silty clay loam. The rates of adsorption of monuron on Chillum silt loam was at the low end of the range, while on the other 3 soils, it ranged intermediate between the 5 triazine herbicides included in the tests. The movement of herbicides in the 4 soils was studied in 3-in diameter columns that were filled to a depth of 1.75 in with soil treated with the herbicides at the rate of 2 lb AI/acre, topped by untreated soil to a total depth of 7 in. Upward movement of water through these columns from a free water supply was used to effect herbicide movement. After 5 days, the columns were sliced into 1-in segments for bioassay, using oat seeds as a sensitive indicator plant. Reduced growth of oats as compared with oats growing in segments from untreated columns indicated the presence of a herbicide. The rate of movement of monuron was very similar to that of the triazine herbicides, with the exception of one which remained predominantly in the lower 2 segments in all soils.

The initial phytotoxicity of the herbicides in the 4 soils was studied by applying a series of 6 concentrations of each herbicide to each soil to determine the concentration, in parts per million by weight, necessary to reduce the fresh weight of oats by 50% (ED_{50}). The ED_{50} values of monuron were intermediate between those of the triazines. For all herbicides, the ED_{50}'s were lowest in the Lakeland sandy loam and highest in the Hagerstown silty clay loam. Harris concluded that phytotoxicity and movement of monuron (and of the triazine herbicides studied) were inversely related to the extent of soil adsorption. The adsorption of monuron was less affected by pH than that of the other herbicides.

In further studies, Harris (1967) found that monuron ranged intermediate between pesticides having the highest and lowest mobility.

Bayer (1967) studied the effects of surfactants on the leaching of monuron and several other substituted urea herbicides in a Yolo sandy loam. The herbicides were applied at a rate equivalent to 10 lb/acre to the top of soil columns with a 2 in diameter and 20 in tall. Several surfactants at rates of 1.0 and 10.0% weight/volume were applied together with the herbicides. Simulated rainfall equivalent to 5 and 10 in of water was applied at the rate of 5 in/hr as the leaching agent. At the end of 24 and 48 hr, the columns were allowed to drain for 48 hr, then they were sectioned into 2-in segments and bioassayed with oat seeds. Most of Bayer's tests were conducted with a pesticide closely related to monuron; but in one comparative set of tests, it was found that the leaching behavior of monuron was similar to that of the related herbicide tested. Several surfactants nearly eliminated any downward movement of the substituted urea herbicides. The author suggested that a sorption complex of the substituted urea herbicide, the surfactant, and the soil may be formed. Cationic surfactants containing the dilauryl moiety were most effective in reducing the downward movement of the herbicides, while related surfactants containg lauryl, dioctyl, and distearyl substitutions had little or no effect on leaching.

Rhodes et al. (1970) studied the movement of monuron and several other herbicides in soils by measuring their R_f (ratio of distance moved by a solute to distance moved by the solvent front) values on thin layer (400 μm) soil chromatograms. Four agricultural soils from different locations were selected, i.e., muck from Florida; Muscatine brown silt loam from Macomb, Illinois; Keyport silt loam from Newark, Delaware; and Cecil loamy sand from Raleigh, North Carolina. The Freundlich isotherm constants (K-values) were determined in soil-water systems. In terms of the mobility classes suggested by Helling and Turner (1968), monuron may be assigned to mobility class 3 (R_f values ranging from 0.35 to 0.64).

The effect of soil pH on the mobility of monuron and the other 4 herbicides was studied in Keyport silt loam by Rhodes et al. (1970). Over a pH range from 5.4 to 8.9, the mobility of monuron was not affected significantly. An estimate of the lateral diffusion of the herbicides was made by dividing the width of appropriate spots on TLC plates by the width of the applied spot. The nonvolatile compounds with the highest mobility showed slightly greater lateral diffusion than those with lower mobility.

Helling (1971a) also used the soil TLC technique in studies of the mobility of 40 pesticides, including monuron, in Hagerstown silty clay loam. In this soil, the R_f value of monuron was 0.48, also placing it into mobility class 3 in the system of Helling and Turner (1968).

In a companion study (Helling, 1971b), the mobility of monuron and 11 other pesticides was determined in 14 different soils selected to include a broad range in clay content (11 to 51%), organic matter content (0.1 to 8.0%), and pH (4.3 to 7.7). For monuron, as well as for the other pesticides studied, there was a general trend toward reduced mobility with increased soil organic matter content. The R_f values of monuron as determined by soil thin-layer chromatography ranged from 0.38 in Berkley silty clay (8.2% organic matter) to 0.84 in Norfolk sandy loam (0.14% in organic matter). The average R_f of monuron was 0.54.

Moyer (1972) and Moyer et al. (1972) studied the adsorption and desorption of monuron and a number of other herbicides with soil colloids, including montmorillonite, kaolinite, silt, and peat. The adsorption of monuron to montmorillonite was found to be reversible after a 24-hr adsorption period, as well as after drying. With a peat preparation, monuron was adsorbed reversibly if desorption was carried out immediately after adsorption. However, after drying, the monuron was irreversibly adsorbed to the peat at 62 to 85% relative humidity. The authors do not believe that degradation of monuron (or of the other herbicides studied) could account for the irreversible adsorption.

Hurle and Freed (1972) investigated the effects of electrolytes on the solubility and soil adsorption of monuron, 2 other substituted ureas, and 3 triazine herbicides. Their objective was not primarily to study adsorption mechanisms per se, but to show the influence of electrolyte concentration on the solubility and adsorption of these herbicides. The solubilities of monuron and the other herbicides were determined in water and in solutions of ammonium, potassium, and calcium chloride at ionic strengths of 0.3 and 0.6. All 3 salts decreased the solubility of monuron (and of the other herbicides); increasing the ionic strength resulted in further lowering of the solubility. By introducing monuron into the electrolyte solutions, the pH was lowered by about 1 pH unit. The decrease in solubility of monuron (and of the other herbicides) in the salt solutions, according to the authors, is simply a "salting out" effect. The salt ions attract around themselves the polarizable water molecules, making the solution more polar and reducing the amount of water molecules available.

The increased adsorption of these herbicides on soil in the presence of rather high electrolyte concentrations is probably due mainly to the decrease of the herbicide solubility. Adsorption studies on 2 monuron-related herbicides suggested that under conditions of high salt concentrations in soil solution (such as those following fertilizer application or soil-drying), more herbicide, expectedly, would be absorbed and more tightly bound. This could result in a longer residual life of the herbicide in the soil and restricted availability for weed control. However, under normal farm conditions, the electrolyte concentration of the soil solution decreases due to uptake by plants and/or dilution by precipitation. The findings and tentative conclusion by Hurle and Freed (1972) may explain certain observations made in other laboratory studies, such as those by Moyer (1972) and Moyer et al. (1972).

Van Bladel and Moreale (1974) investigated the adsorption of monuron and another urea herbicide by 2 montomorillonite clays. They were a Volclay bentonite from Wyoming with a lattice charge originiating from tetrahedral and octahedral layers, and a typical montmorillonite from Camp Berteau, Morocco, with a lattice charge only from octahedral layers. The authors determined the solubility of monuron at 3.5 and 26.5°C in plain water, and at different electrolyte levels ranging from 0.005 to 3 Normal (N). The effect of salt concentration on the solubility of both substituted ureas was almost negligible at 0.1 N, but pronounced at 1 N, and even more so at 3 N. Salt concentration had little or no influence on the adsorption of monuron by the clay minerals up to an ionic strength of approximately 0.5 to 0.1 N; above that range, the adsorption increased and became very dependent on the ionic strength. The adsorption of both herbicides was greater on hydrogen-saturated montmorillonite than on sodium-, calcium-, or magnesium-saturated montmorillonite. In general, monuron adsorption was greater than that of the other herbicide tested. Adsorption of both chemicals was lower on the Camp Berteau clay which had only octahedral substitution.

Briggs (1969) investigated the relationships between the molecular structure of herbicides and their sorption by soils. Sorption isotherms were determined for 22 substituted phenylurea herbicides, including monuron, by a wet slurry technique on 4 neutral Rothamsted soils, containing 1 to 4% organic matter. The substituted phenylureas yielded a linear relationship between the log of the partition coefficient and Hammett's sigma constant for meta- and para-substituents in the phenyl ring. Even better fit was obtained by using a combination of the sigma constant and the Taft constant for substituents of the side-chain nitrogen. The author concludes that for phenylureas with short alkyl side chains, ring deactivation by ring substituents, or by replacement of a methyl group on the side-chain nitrogen by hydrogen or methoxy, appears to be the factor controlling sorption, possibly through charge-transfer bonding to activated sites on organic matter.

Kazarina (1965) investigated the translocation of monuron in soil. Air-dried samples of several different soils were studied in laboratory soil column experiments. Column surfaces were treated with monuron at a rate equivalent to 4.0 lb/acre (4.5 kg/ha), and the soil moisture was kept at 40 and 70% of water capacity for 1 month. Oat bioassays of soils from different column layers indicated that at 40% soil moisture, monuron remained within the upper 1.0 in (2.5 cm) of the soil surface in both soils, while at 70% of water capacity, monuron penetrated to about 3.0 in (7.5 cm) in the loamy sand, and to about 2.0 in (5.0 cm) in the medium sandy loam. However, in both soils the majority of the monuron applied remained in the surface soil layer. When simulated rainfall was applied to the same soil columns, almost all of the monuron remained in the 0 to 1.0 in (0 to 2.5 cm) layer following irrigation with 50 ml of water. Following irrigation with 200 ml of water, the major portion of the monuron applied still remained in the surface soil layer, but traces were found in deeper soil layers.

Spiridonov and Kamenskii (1971) investigated the stability of monuron in 5 different soils in relation to soil temperature, humidity, and oxygen supply. The phytotoxicity of monuron (applied to soil samples at the rate of 3 mg/kg) to oats declined more rapidly when the treated soils were incubated at 40 to 60°C with high humidity under anaerobic conditions, than when incubation occurred at 0 to 30°C under aerobic conditions. The different soil types studied had little effect on the loss of phytotoxicity of monuron.

Sheets (1964) reviewed known facts concerning the disappearance of monuron and other substituted urea herbicides from soil. His presentation includes information available from approximately 1965, although there is little specific information on monuron. However, many studies on monuron's disappearance from soil have been carried out since that time.

Field and Greenhouse Studies - Hill et al. (1955) studied the persistence of monuron and a related urea herbicide under field conditions over a 2-yr period in plots established on silt loam soils in Delaware and Louisiana, on a loamy sand in North Carolina, and on a sandy soil in Florida. When monuron was applied once at the rate of 1 lb/acre, 84 to 85% of the applied rate disappeared within 12 months from sand, loamy sand, and silt loam soils. Following one application of 2 lb/acre of monuron, 89 to 98% of the applied rate disappeared from the same soils within 12 months. When a second application of monuron at 1 lb/acre was made after 12 months to the plots treated the preceding year at 1 lb/acre, 69% of the total quantity applied disappeared within 8 months after the second application in the silt loam (Louisiana) plots; 73 and 19% of the combined rate disappeared within 12 months after the second application in the sandy (Florida) and sandy loam (North Carolina) plots, respectively. When a second application of monuron at 2 lb/acre was applied to plots that had received 2 lb/acre of monuron the preceding season, 76% of the combined rate disappeared within 8 months after the second application of the silt loam plots, and 71% within 12 months after the second application in the sandy loam plots. The overall rate of disappearance of monuron in all plots and at all application rates was 83% during a 12-month period. In all tests, phytotoxic concentrations from 1 and 2 lb/acre applications disappeared from the treated soils within 4 to 8 months after application. A 4 lb/acre application was reduced to nonphytotoxic levels in cultivated soils 12 to 16 months after the initial application.

In a lysimeter leaching study carried out in the greenhouse, monuron was applied to the surface of 8 in diameter columns 36 in tall, at the rate of 10 lb/acre; the columns were leached with the equivalent of 72 in of simulated rainfall, applied at the rate of 1 in/day for 5 days. After 2 rain-free days, 1 in of rainfall per day was again applied for 5 days, and the same procedure repeated until the total amount of 72 in had been applied over a period of approximately 90 days. Leachate samples were collected, and upon completion of the leaching phase, soils were removed from the lysimeters in separate 4 in layers and analyzed. Parallel tests were carried out in 11 different soil types from 7 locations throughout the United States. At the conclusion of the test, the amounts of monuron remaining in the soils varied from 4 to 62%; those found in the leachate varied from 0 to 56%; those unaccounted for varied from 38 to 85%. The authors concluded that leaching can occur under conditions of extremely high rainfall on a porous soil. However, under field conditions and at application rates of 1 to 2 lb/acre, removal of monuron from the soil by percolating water is not regarded as a major cause of disappearance because essentially all of the monuron recovered upon sampling is found in the upper 0 to 4 in layer of soil.

Based on these findings, combined with the results of studies on the biological degradation of monuron reviewed in the preceding subsection, Hill et al. (1955) concluded that the microorganisms are a primary factor in the disappearance of monuron residues from soil. Preliminary observations from chemical studies indicate that hydrolysis or oxidation of monuron proceed slowly at ambient temperatures. Photodecomposition can occur and may be a significant factor in the disappearance of monuron residues from soil when little rainfall occurs after application and the chemical remains on the soil surface.

Rahn and Baynard (1958) investigated the persistence and penetration of monuron in asparagus beds in Delaware on a loamy sand soil using the oat bioassay technique for detection of monuron residue. In a 3-yr study, monuron did not persist from one year to the next when applied twice annually at the rate of 1.6 lb/acre. When twice this rate was used, an estimated 0.3 to 0.4 lb/acre of monuron persisted from one year to the next, but there was no accumulation. Monuron disappeared more rapidly following the second application, applied in mid-summer, than following the spring application. Following the mid-summer application, 36% of the quantity applied (1.6 lb/acre) disappeared during the first month, while only 14% of the same quantity applied in the spring disappeared during the first month. Small quantities of monuron (maximum 0.2 lb/acre) penetrated to the 4- to 8-in soil horizon at all rates used. Monuron residues had completely disappeared from this soil layer by 1 November. Cultivation accelerated disappearance of monuron from the treated soil. The herbicide disappeared more rapidly from soils with higher organic matter content. In periods of below-normal rainfall, irrigation slightly accelerated the disappearance of monuron from the top 4 in of soil, while it did not increase movement to the 4- to 8-in soil layer. When rainfall was near normal, irrigation had no effect on persistence or penetration of monuron.

Welker and Brogdon (1972) investigated the effects of continued use of monuron and 8 other herbicides. This test was conducted in a Freehold sandy loam with an organic matter content of 1.6%. Monuron was applied at the rate of 2.2 kg/ha (about 2.0 lb/acre) either once or twice each year for 7 consecutive years. Monuron and several other herbicides gave excellent weed control; 1 application of monuron was as effective for weed control during the cutting season as 2 applications, but weed control in the fall was improved by making a second monuron application. There was no indication that the continuous use of monuron (or of any of the other herbicides studied) resulted in a build-up of residues in the soil or in plants, or in any deleterious effect on the crop yield.

Shadbolt and Whiting (1961) compared the persistence of monuron and a related herbicide in Romona sandy loam under field conditions. Monuron was applied at the rates of 2, 4, and 8 lb/acre. Fifty percent of the quantities applied disappeared from the treated soils in 4 to 5 months, whereas 8 to 9 months were required for the other herbicide tested to decline to 50% of the rate applied.

Arle et al. (1965) and Hamilton and Arle (1968) reported on extensive investigations on the disappearance of monuron and several other herbicides from irrigated soils in the southwestern United States. Permanent field plots were established at 2 locations in Arizona, and one in California. In tests in a silt loam soil at Tolleson, Arizona, monuron and a related herbicide were applied to cotton as layby treatments each year from 1954 to 1962. The herbicides were applied as a broadcast, directed spray at rates of 0.8 and 1.6 lb/acre. The plots were flood-irrigated 8 times during each growing season. Annual irrigation totaled 40 in/yr, and 4 of the irrigations, totaling 16 in of water, occurred after application of the herbicides. Injury to cotton in the form of chlorosis of the foliage was noticed each year after the annual application of monuron, persisting for 4 to 5 weeks after treatment. In 1958 and each year thereafter, characteristic symptoms usually associated with monuron injury were noticed on the foliage of a few cotton seedlings in plots treated the previous 4 seasons at the higher rate of monuron. After a period of retarded development, these plants resumed normal growth. Monuron did not affect the yield of cotton in the first 7 yr of this test. In the eighth and ninth yr, the yield from plots treated annually with monuron at 1.6 lb/acre were lower than those from untreated plots.

Arle et al. (1965) conducted a similar experiment on sandy loam in Arizona for 5 successive seasons (1957 to 1961). Monuron was applied at the rate of 1 lb/acre each year before the fourth irrigation. There was no evidence of injury to cotton seedlings from carry-over of monuron from the previous season, and there were no adverse effects on cotton yield from the annual monuron treatments compared to untreated controls. A third set of field tests were run on sandy loam in California. Monuron was applied at rates of 1.0 to 1.5 lb/acre as a broadcast, directed spray to furrow-irrigated cotton at layby. Herbicide applications were made annually during July or early August from 1956 through 1961. After harvest of cotton each year, the experimental area was seeded to barley. During the study period, there were no apparent effects on emergence or development of cotton seedlings due to carry-over of monuron residues from the previous year's application, and cotton yields were not adversely affected by either rate of monuron. Stands of barley sown in the winter after cotton harvest were reduced by both rates of monuron in all except one year. Monuron caused more injury to winter-sown barley than a related herbicide tested in parallel plots.

Dawson et al. (1968) studied the residues of 3 urea herbicides, including monuron, remaining in a furrow-irrigated vineyard on Warden silt loam soil. Monuron (from a wettable-powder formulation) was applied at the rate of 2.5 lb AI/acre annually for 6 yr (1958 through 1963). The herbicides were sprayed under the trellises of Concord grapes each year in late February or early March. For the first 4 yr, monuron was also applied (to different plots) at the rate of 7.2 lb AI/acre, but this treatment was discontinued after 1961 because of severe injury to grape vines. Shortly after application, the study herbicides were incorporated into the upper 2 in of soil by hand tools or a small, power-driven rotary tiller. After the last of the 6 annual applications, residues remaining at different depths were determined by the oat bioassay technique. Monuron residues found were as follows:

Lb/acre		Residues - ppm weight Soil depth - inches				Total lb/acre upper 12 in
Yearly	Total	0-2	2-4	4-8	8-12	
2.4*	14.4	1.49	0.75	0.09	0.00	1.6
7.2**	28.8*	0.54	0.22	0.13	0.06	0.8

---

* There was a 1 yr period between the last application of monuron at this rate and the collection of samples for residue analysis.

** Monuron at 7.2 lb/acre was not applied at the last 2 of the 6 scheduled annual application dates. There was a 3 yr period between the last application of monuron and the collection of samples for residue analysis.

This data shows that most of the residual herbicide was located close to the soil surface. The total quantity of monuron remaining 1 yr after the last annual application at the rate of 2.4 lb/acre amounted to two-thirds of one annual application. Three years after the last of 4 annual applications of monuron at 7.2 lb/acre, the residue remaining had been reduced to 11% of one annual application. These findings indicate that persistence of phytotoxic residues for at least 1 yr after application can be expected under the conditions of this experiment. Injury to sensitive plant species may occur following annual applications of monuron. Therefore, the authors recommended that monuron should not be used on a tolerant crop the season before rotating to a sensitive crop, especially in fields under furrow irrigation.

Hill (1971) reported on a long-term study on the rate of disappearance of monuron initiated at Newark, Delaware, in the spring of 1952. The test area was on a Keyport silt loam with restricted internal drainage, with average annual rainfall of 40+ in. Experimental plots were treated with monuron at the rate of 2.0 lb/acre each spring for 18 consecutive years, for a total application of 36 lb. Each year, the soil was disced to a depth of 4 in and rolled for seedbed preparation. Prior to retreatment each year, soil samples were taken at 0 to 4, 4 to 8, and 8 to 12 in depths and bioassayed with oats in the greenhouse. The results indicated that no phytotoxic residues were present in the soil as determined by normal growth of the oats. Hill concludes that there was no accumulation of phytotoxic levels of monuron under these conditions. Less than 1 lb/acre of monuron was present in the soil after 18 annual treatments of monuron at the rate of 2 lb/acre/year.

Upchurch et al. (1968) studied the soil sterilization properties of monuron and 3 other herbicides on a Norfolk sandy loam soil under field conditions in North Carolina. The purpose of these tests was to identify herbicides and application parameters that would result in reasonable soil sterility without excessive lateral herbicide movement. Monuron and the other herbicides were applied initially to test plots at 40 lb/acre. This application was followed by one of the following retreatment schedules: no retreatment, retreatment at 20 lb/acre annually for 3 yr, or retreatment in the second or third year only. Initial treatments were made in April 1960, and retreatment each spring thereafter as required by the retreatment schedule. Of all the herbicides studied, monuron acted most rapidly. A single reapplication of 20 lb/acre of any of the 3 herbicides was adequate to restore a reasonable level of vegetation control, regardless of whether the retreatment occurred 1, 2, or 3 yr after the initial 40 lb/acre treatment. Annual retreatment was necessary to maintain a continuously high level of sterility. All 3 herbicides caused injury to vegetation downslope from the treatment area. Lateral movement of monuron was less severe than with other pesticides tested.

Isensee et al. (1973) initiated an investigation in 1954 at Beltsville, Maryland, in order to determine the initial and long-term results of application of massive quantities of monuron and several other herbicides. Field plots 4 m^2 in size, surrounded by concrete borders 0.2 m wide by 0.9 m deep, were established, with concrete borders projecting about 20 cm above the plot surface to prevent lateral movement of herbicides or revegetation from adjacent plots by rootstock propagation. The soil in the area was a Matapeake silt loam (pH 5.3, organic matter 1.5%, sand 38.4%, silt 49.4%, and clay 12.2%). Monuron was applied in May of 1954 at rates of 56, 112, and 224 kg/ha (about 50, 100, and 200 lb/acre), rates exceeding recommended agricultural rates by 10 to 100 times. Vegetative responses were determined 1, 2, 3, and 15 yr after treatment.

After 3 yr, vegetation covered 80 to 89% of the soil surface in the monuron-treated plots. The authors concluded that under the conditions of this test, massive rates of monuron (as well as of most of the other herbicides studied) dissipated in 1 to 3 yr. Bioassays in 1968, 14 years after the treatment, indicated no residual phytotoxicity in the monuron-treated plots. Among the phenylurea herbicides included in this study, monuron was the second most rapidly dissipated.

The authors suggest that several processes, including microbial metabolism, adsorption to mineral and organic colloids, volatility, and leaching may account for this dissipation. Based on adsorption characteristics, monuron is one of the most available herbicides tested for microbial degradation and was consequently degraded more rapidly than 2 other related herbicides. The authors further observed that the water solubilities of monuron and the 3 other phenylurea compounds appeared to be positively correlated with their residual phytotoxicity.

Pimentel (1971) reported that monuron applied at the rate of 1 to 3 lb/acre persisted for 3 to 6 months in a moist loam soil with little or no leaching under summertime conditions in a temperate climate. Holly and Roberts (1963) found that monuron applied at 0.5 lb/acre persisted in the soil for 28 weeks. Birk (1955) reported that, following application at the rate of 20 lb/acre, monuron residues persisted in the soil for 3 yr.

Several additional greenhouse and field soil-persistence tests with monuron, conducted mostly in the 1950's, were reviewed by Sheets (1964). The results of these tests are generally in agreement with the field observations. Among the phenylurea herbicides, the rate of degradation of monuron was usually intermediate.

Mullison (1970), in a review of the significance of herbicides to nontarget organisms, concluded that 80% of the quantities of monuron and related herbicides applied at field rates were found to have disappeared during the year following application in most climatic and edaphic conditions. Repeat treatment disappeared at about the same rate as the original treatments. The use of monuron in citrus orchards or asparagus plantings did not result in residue buildup in the soil, but if the land use were to be changed, and if it were to be planted immediately with a sensitive crop, there probably would have been a risk of damage. The residual phytotoxicity of monuron in the field, as summarized in this review, lasted 5 to 6 months following applications at 2 to 4 lb/acre, and 12 months following application at 4 to 6 lb/acre. In the greenhouse, residual phytotoxicity persisted for 1 to 3 months following applications at 2 to 5 lb/acre.

Several Russian investigators also studied the soil persistence of monuron under different conditions. Kuznetsov and Mikhailov (1969) reported on the residual action of monuron and several other herbicides in the second and third year after the planting of an apple tree nursery in a peat soil. Monuron was applied (rate not specified) before planting of the apple seedlings. Some residual herbicidal efficacy was retained in the third year, but monuron was less persistent than another herbicide tested.

Khubutiya and Gigineishvili (1971) studied the residual effectiveness of monuron applied in the early spring at the rate of 8.9, 12.0, and 14.2 lb/acre (10, 13.5 and 16 kg/ha) in citrus plantations. Monuron (and several other herbicides studied) penetrated 15.7 in (40 cm) into the soil during the first 2 months after application. Small residues were detected in citrus leaves following the 2 higher application rates. Monuron did not accumulate when applied at the rate of 8.9 lb/acre for several years in succession.

Spiridonov, Kamenskii and Yakolev (1970) and Spiridonov et al. (1970, 1972) studied the effectiveness and persistence of monuron and several other herbicides under humid, subtropical conditions in different soils. They found that monuron was rapidly leached down into the 31- to 39-in (80 to 100 cm) soil layer in "red-earth soil" under intensive rainfall; only 0.7 to 1.4 lb/acre (0.8 to 1.6 kg/ha) remained in the upper 0- to 4-in (0 to 10 cm) soil level 110 days after application (initial rate of application not given). Within an additional 40 days, residues of monuron disappeared from the soil due to the action of soil microorganisms. Monuron showed no significant toxic effects on soil bacteria, fungi, or cellulolytic microorganisms. However, within 40 to 70 days of application, both herbicides temporarily reduced the activity of the soil microflora and that of several soil enzymes. Increased soil concentrations of available potassium, nitrogen and phosphorus were observed in the soil during this period, except under weed-free sections of the soil where there were no effects on the mobility of these nutrients.

In meadow-bog soil, monuron applications of 7.1 lb/acre (8 kg/ha) were completely inactivated in 110 days. When applied at 10.6 and 14.2 lb/acre (12 and 16 kg/ha), the herbicides were inactivated in 150 days by the combined action of microorganisms and chemical hydrolysis. The herbicide treatments did not affect the total numbers of bacteria or oligonitrophils in the soil but, during the period 40 to 70 days after treatment, the total number of soil fungi decreased, while the activity of cellulose-metabolizing microorganisms increased.

Spiridonov, Kamenskii and Yakolev (1970) investigated the reasons for the rapid loss of herbicidal activity of monuron and a related herbicide in water-logged meadow and red subtropical soils. The leaching rate of both herbicides was 2 to 3 times greater in the subtropical red soil than in soils in temperate climate. Following applications at 8.9 and 17.8 lb/acre (10 and 20 kg/ha), both herbicides penetrated to a depth of 15.7 in (40 cm) in the water-logged meadow soil, and to 19.7 to 27.6 in (50 to 70 cm) in the red soil in 1.5 to 2.5 months. The authors contended that high moisture saturation and temperature during the 5 to 6 months of the growing season promoted intensive microbial degradation of monuron.

Residues in Water

According to Hurle and Freed (1972), the solubilities of monuron and 2 other herbicides (in parts per million) at 25°C in water and in solutions of 3 different electrolytes at 2 different ionic strengths of each are as follows:

	H_2O (pH 5.7)	KCl (pH 4.7)		NH_4Cl (pH 4.5)		$CaCl_2$ (pH 4.5)	
		Ionic Strength		Ionic Strength		Ionic Strength	
		.03	.06	.03	.06	.03	.06
Monuron solubilities:	262	220	195	228	217	226	215

It is noteworthy that the various electrolytes decrease the water solubility of monuron as well as of the 2 related herbicides, as already pointed out above in regard to the influence of this effect on the adsorption of these herbicides in the soil.

E. I. du Pont de Nemours and Company (1972) reported that the water solubility of monuron is approximately 230 ppm at 25°C in distilled water.

Frank (1966) studied the persistence and distribution of monuron and a related herbicide in an aquatic environment. Objectives were to determine the distribution of the herbicides between soil and water, and their persistence in water and submersed soil. The soil used in the study was an amorphous deposit from a local irrigation canal consisting of 17% clay, 47% silt, 36% sand, and

2.31% organic matter. Air-dry soil was placed in metal tubs 17 in high with a diameter of 22 in and covered with 6 in of water. After allowing the tubs to stabilize for 1 month, wettable powder suspensions of the herbicides were sprayed over the water surface at a rate equivalent to 40 lb/acre. Samples of water and soil were taken from each tub at intervals of 1, 2, 4, 8, 16, 32, 64, and 128 weeks after treatment and analyzed chemically for herbicide residues. Appreciable loss of monuron did not occur until 16 weeks after treatment, and the disappearance rate was greatest between the sixteenth and thirty-second week during which 40% of the monuron was lost. When about 50% of either herbicide was lost, their disappearance continued at a reduced rate until the end of the experiment. Approximately 15% of the monuron, and 39% of the other herbicide applied, remained after 128 weeks. More monuron was found in the water than in the soil during the first 42 weeks. After that time, most of the monuron was found in the soil, primarily in the top 4 in. Monuron moved down in the soil more readily than the other herbicide tested. Both herbicides permeated the soil very rapidly, within the first week after treatment. The author points out that many submersed soils, including the soil used in his study, seem to have much of their pore space filled with gases. Evaporation from the soil solution, followed by diffusion through the gas-filled pore space, may have accounted, at least in part, for the rapid transport of the herbicides to a depth of 8 in. According to Frank, "the total quantities of monuron recovered from water exceeded those recovered from soil throughout the first 16 weeks of sampling."

Eichelberger and Lichtenberg (1971) investigated the persistence of monuron and a number of other common pesticides in raw river waters over an 8-week period. Aliquots of 10 µg/l of monuron from a freshly prepared 0.1% solution in acetone were injected into samples of raw river water from the Little Miami River, a relatively small stream receiving domestic and industrial wastes and farm runoff. The dosed raw river water was kept in the laboratory in closed glass containers at room temperature and exposed to natural and artificial light. Under these conditions, 80% of the original concentration of monuron was recovered at 0 time, 40% remained after 1 week, 30% after 2 weeks, and 20% after 4 weeks; no monuron was detected after 8 weeks. The only other phenylurea herbicide included in these tests disappeared more rapidly than monuron; 20% of the applied rate was still present after 2 weeks, and 0 after 4 weeks.

Mikhailov (1967) studied the physical and chemical properties of monuron and a related urea herbicide to establish an experimental basis for permissible concentrations of these herbicides in reservoir waters. Monuron could be detected by smell at 5 mg/l, and by taste at 6.6 mg/l. The smell was very stable. Monuron increased the biological oxygen demand (BOD). Monuron began to inhibit ammonification and nitrification processes at 25 to 50 mg/l. Based on these properties, and on the acute and chronic toxicity of monuron to laboratory rodents, the permissible concentration was established at 5 mg/l for monuron.

Bersonova (1967) studied the effects of monuron applied in irrigation water on the yield of cotton being irrigated with the treated water in an experiment simulating field conditions. Cotton plants grown in large pots were watered with aqueous solutions of monuron at 1.04, 0.44, and 0.22 mg/l. Plants watered with herbicide-free water served as controls. The higher concentrations of monuron caused some growth retardation. The cotton yield was decreased only by the highest concentration of monuron; it was not significantly different from the controls in all other treatments. The author concluded that the growth and development of cotton plants would not be affected by concentrations of monuron that would be used in field practice. Therefore, irrigation water could be used for irrigation of cotton plants while the irrigation system is being treated with herbicides.

Some researchers feel that in order to determine what photo conversions are possible in the environment, photosensitization should not be ignored, and that chemicals in the environment obviously do not exist in isolation. Translocation through plants or dispersion in aqueous media that contain microorganisms enhance the possibilities of contact with photosensitizers such as flavins and chlorophylls.

As reported in the subsection on lower aquatic organisms, Sweetser (1963) found that FMN caused photochemical inactivation of monuron (and of other substituted phenylureas).

Residues in Air

Vengerskaia and Kur (1969) developed a method for the determination of small quantities of monuron in air, based on the property of urea derivatives to hydrolyze quantitatively at elevated temperature with the formation of aromatic amines. Standard solutions of monuron (10 to 100 μg/ml) are placed in colorimetric test tubes to which alcohol and alkali are added. Upon completion of hydrolysis, diazotization is effected in an acetate buffer solution with a mixture of potassium nitrite and bromide. After combining the reaction products in an alkaline medium with alphanaphthol, the monuron content is determined photometrically. According to the authors, the method is simple, sufficiently sensitive, and applicable to studying working conditions when monuron is being applied to the soil. However, no examples of practical application of the method were included.

Hill (1971) reported that the vapor pressure of monuron is extremely low, for example, 3.4×10^{-6} mm Hg at 50°C. He pointed out that water is 30 million times more volatile than monuron. Thus, Hill concluded that loss of monuron from the soil into the atmosphere by volatilization is negligible.

Residues in Nontarget Plants

Brandes and Heitefuss (1971) reported that winter and spring wheat showed an increased incidence of mildew (*Erysiphe graminis*) after application of monuron, another urea herbicide, and triazine herbicides. When this observation was followed up in greenhouse experiments, it was found that treatment of infected wheat with these herbicides resulted in a reduction of *E. graminis* and of another fungal pathogen of wheat, *Cercosporella herpotrichoides*. The incidence of mildew on herbicide-treated wheat in the greenhouse approached that of untreated control plants during the early stages of development of the plants, but was higher in the herbicide-treated plants during the blooming stage. The weight and mildew incidence of herbicide-treated wheat during the early stage was increased by supplementing the plants with glucose, or by exposing them to higher light intensities. Further herbicide treatment decreased the mildew incidence under all conditions. The authors contended that the difference in disease incidence was related to changes in the physiological conditions of the host plant induced by the herbicides.

Bourke et al. (1964) studied the effect of monuron on the metabolism of glucose in pea roots by means of ^{14}C-labeled glucose. Monuron was found to slightly inhibit both the pentose cycle and glycolysis. Of the two pathways, the pentose cycle was more strongly inhibited. Monuron appeared to have no effect on anabolic reactions and an insignificant effect on catabolic processes.

Frear and Swanson (1972) isolated 2 polar *O*-glucoside metabolites of monuron-14^{C} from cotton leaves. The metabolites identified as β-D glucoside of 3-(-4 Chlorophenyl)-1-hydroxymethyl-1-methylurea and 3-(4-Chlorophenyl)-1-hydroxymethylurea provide direct evidence for the formation of N-hydroxymethyl intermediates in the oxidative N-demethylation of substituted phenylurea herbicides in higher plants. In the same paper the authors reported that *in vivo* and *in vitro* tests failed to demonstrate any significant aniline metabolites. This agrees with the work of Geissbuhler (1969). The authors concluded that results from previous studies, notably, Smith and Sheets (1967) and Swanson and Swanson (1968) that demonstrated the degradation of substituted phenylurea herbicides in higher plants may have reflected impurities in the sample or photochemical or microbial degradation before absorption by plant tissues.

Bioaccumulation, Biomagnification, and Environmental Transport Mechanisms

Only one paper on the uptake of monuron has been found. Komarovsky (1972) applied "Monurox" (10% monuron, 10% TCA) to artificial ponds containing *Leuciscus idus*, *Rutilus rutilus*, and *Leuciscus cephalus* at a rate of 40 kg/ha AI (20 kg/ha of monuron) equivalent to approximately 17.88 lb/acre of monuron. The concentration of monuron in the water ranged from 0.1 to 0.3 mg/l. After 5 days, *R. rutilus* had monuron concentrations of 15 ppm in the heart and 0.42 ppm in the gills; after 60 days, 0.13 ppm monuron was found in muscle. *L. idus* muscle contained concentrations of monuron of 0.95 ppm after 10 days, 0.30 ppm after 15 days, 0.59 ppm after 18 days and only trace amounts after 60 days; after 15 days 1.2 ppm monuron was found in the skin. In *L. cephalus*, brain tissue contained 5.3 ppm monuron after 5 days, and muscle contained 1.5 ppm after 15 days.

Compared to other pesticides, monuron appears to be relatively resistant to photodecomposition by itself. However, one report indicates that it is readily photodegraded in the presence of FMN, a photodesensitizer. In another study, p-chloroaniline was tentatively identified as one of several minor photodegradation products of monuron. Other tests showed that the FMN-sensitized photolysis of p-chloroaniline yielded 4,4'-dichloroazobenzene and 4-chloro-4'-(4-chloroanilino)azobenzene, but this photolysis did not take place in the absence of FMN. No reports were found on the possible occurrence, rate or significance of these transformations under field conditions.

References

Akopyan, E. A., and A. G. Agaronyan, "Effect of Monuron, Diuron, and Simazine on Soil Microflora in a Vineyard in Armenia," Khim. Sel. Khoz., 6(11):850-851 (1968).

Alabaster, J. S., "Survival of Fish in 164 Herbicides, Pesticides, Fungicides, Wetting Agents, and Miscellaneous Substances," International Pest Control, 11:29-35 (1969).

Arle, H. F., J. H. Miller, and T. J. Sheets, "Disappearance of Herbicides from Irrigated Soils," Weeds, 13:56-60 (1965).

Atkins, E. L., E. A. Greywood, and R. L. Macdonald, "Toxicity of Pesticides and Other Agricultural Chemicals to Honey Bees," University of California, Agricultural Extension Report M-16, (1973).

Audus, L. J., "The Action of Herbicides and Pesticides on the Microflora," Meded. Rijksfac. Landbouwwetensch. Gent., 35(2):465-492 (1970).

Babak, N. W., "Azotobacter Sensitivity to Some Antibiotics and Herbicides," Mikrobiologiya, 37(2):388-444 (1968).

Baumgartner, L. L., "A Case History of Misapplication of CMU for Aquatic Weed Control," Proc. Northeastern Weed Control Conf., 9:559-562 (1955).

Bayer, D. E., "Effect of Surfactants on Leaching of Substituted Urea Herbicides in Soil," Weeds, 15(3):249-252 (1967).

Bersonova, K. A., "Use of Collector Water, Treated by Herbicide, for Watering of Cotton," Khim. Sel. Khoz., 5(4):277-280 (1967).

Birk, L. A., "Penetration of and Persistence in Soil of the Herbicide 3-(p-Chlorophenyl)-1,1-dimethylurea (CMU)," Can. J. Agr. Sci., 35:377-387 (1955).

Bond, C. E., R. H. Lewis, and J. L. Fryer, "Toxicity of Various Herbicidal Materials to Fishes" contained in: C. M. Tarzwell (compiler), Biological Problems in Water Pollution, Seminar Trans., Cincinnati, Ohio, Robert A. Taft San. Eng. Center Technical Report W60-3 (1959).

Bourke, G. B., J. S. Butts, and S. C. Fang, "Effect of Various Herbicides on Glucose Metabolism in Root Tissue of Garden Peas," Weeds, 12:272-276 (1964).

Braginskii, L. P., L. A. Sirenko, N. M. Stetsenko, A. I. Merezhko, V. V. Arendarchuk, and V. D. Bereza, "Organic Algicides," Tsvetenie Vody, 2:169-186 (1969).

Brandes, W., and R. Heitefuss, "Side Effects of Herbicides on Erysiphe graminis and Cercosporella herpotrichoides on Wheat. I. Development of Disease Under Influence of the Herbicides," Phytopathol. Zeitschr., 7;(4)357-371 (1971).

Briggs, G. G., "Molecular Structure of Herbicides and Their Sorption by Soils," *Nature* (London), 223(5212):1288 (1969).

Butler, P. A., "Commercial Fisheries Investigations," Contained in: *Pesticide Wildlife Studies*, U.S. Fish and Wildlife Service Circular, 167:1-25 (1963).

Butler, P. A., "Effects of Herbicides on Estuarine Fauna," *Proc. South. Weed Control Conf.*, 18:576-580 (1965).

Chunderova, A. I., and T. P. Zubets, "Effect of Herbicides on Nitrifying Bacteria from Sod-Podzolic Soils," *Mikrobiologiya*, 39(5):887-891 (1970).

Crosby, D. G., and R. K. Tucker, "Toxicity of Aquatic Herbicides to *Daphnia magna*," *Science*, 154:289-291 (1966).

Danuta, K., "Effect of Herbicides on Oxygen Uptake by Soil," *Rocz. Nauk Roln*., Ser. A, 93(1):125-130 (1967).

Davis, H. C., and H. Hidu, "Effects of Pesticides on Embryonic Development of Clams and Oysters and on Survival and Growth of the Larvae," *Fish. Bull.*, 67(2):393-404 (1969).

Dawson, J. H., V. F. Bruns, and W. H. Clore, "Residual Monuron, Diuron, and Simazine in a Vineyard Soil," *Weed Sci.*, 16(1);63-65 (1968).

DeWitt, J. B., C. M. Menzie, J. W. Spann, and C. Vance, "Evaluation of Chemicals: Toxicity Tests on Birds," Pesticide-Wildlife Studies, Fish and Wildlife Service Circular 199, U.S. Department of Interior (1963).

E. I. duPont de Nemours and Company, "Monuron/Technical Data Sheet," Biochemicals Department, Wilmington, Delaware (1973).

Edson, E. F., "The Risks of Pesticides to Fish," *World Crops*, 10:281-283 (1958).

Edwards, C. A., "Effects of Herbicides on the Soil Fauna," *Proc. British Weed Control Conf*., 3:1052-1057 (1970)

Eichelberger, J. W., and J. J. Lichtenberg, "Persistence of Pesticides in River Water," *Environ. Sci. Technol*., 5(6):541-544 (1971).

Engelhardt, G., P. R. Wallnofer, and R. Plapp, "Degradation of Linuron and Some Other Herbicides and Fungicides by a Linuron-Inducible Enzyme Obtained from *Bacillus sphaericus*," *Appl*. *Microbiol*., 22(3):284-288 (1971).

Fox, C. J. S., "The Effects of Five Herbicides on the Numbers of Certain Invertebrate Animals in Grassland Soil," *Can. J. Plant Sci*., 44:405-409 (1964).

Frank, P. A., "Persistence and Distribution of Monuron and Neburon in an Aquatic Environment," *Weeds*, 14(3):219-222 (1966).

Frear, D. S., and H. R. Swanson, "New Metabolite of Monuron in Excised Cotton Leaves," *Phytochem*. 11:1919-1929 (1972).

Geissbuhler, H., "The Substituted Ureas," Degradation of Herbicides, P. C. Kearney and D. D. Kaufman (eds.), Marcel Dekker, New York (1969).

Goguadze, V. D., "Effect of Herbicides on Azotobacter Development in Some Soils of Western Georgia," Agrokhimiya, 3:99-103 (1968).

Goguadze, V. D., "Change in the Composition of Soil Microflora During the Use of Herbicides in Various Stages of Grapevine Development Under Alluvial Soil Conditions," Subtrop. Kul't., 5:139-143 (1969).

Hachimori, A., Y. Nosoh, and N. Sone, "Effects of Photosynthetic Inhibitors on the Respiration of Yeast Mitochondria," J. Biochem. (Tokyo), 64(1):119-121 (1968).

Hale, M. G., F. H. Hulcher, and W. E. Chappell, "The Effects of Several Herbicides on Nitrification in a Field Soil Under Laboratory Conditions," Weeds, 5:331-341 (1957) reprinted in D. Pimentel, Ecological Effects of Pesticides on Nontarget Species, Executive Office of the President, Office of Science and Technology, Superintendent of Documents, U.S. Government Printing Office, Washington, D.C. (1971).

Hamilton, K. C., and H. F. Arle, "Herbicide Residues in Irrigated Soils" Prog. Agr. in Arizona, 21(2):16-17 (1968).

Harris, C. I., "Adsorption, Movement, and Phytotoxicity of Monuron and s-Triazine Herbicides in Soil," Weeds, 14(1):6-10 (1966).

Harris, C. I., "Movement of Herbicides in Soil," Weeds, 15(3):214-216 (1967).

Heath, R. G., J. W. Spann, E. F. Hill, and J. F. Freitzer, "Comparative Dietary Toxicities of Pesticides to Birds," Special Scientific Report, Wildlife No. 152, U.S. Department of the Interior, Fish and Wildlife, Bureau of Sport Fisheries and Wildlife (February, 1972).

Helling, C. S., "Pesticide Mobility in Soils II. Applications of Soil Thin-Layer Chromatography," Soil Sci. Soc. of Amer. Proc., 35(5):737-743 (1971a).

Helling, C. S., "Pesticide Mobility in Soils III. Influence of Soil Properties," Soil Sci. Soc. of Amer. Proc., 35(5):743-748 (1971b).

Helling, C. S., and B. C. Turner, "Pesticide Mobility: Determination by Soil Thin-Layer Chromatography," Science, 162:562-563 (1968).

Hill, G. D., "Characteristics of Herbicides by Chemical Groups I. Substituted Ureas II. 'Hyvar' X Bromacil," 23rd Annual California Weed Conference Proceedings, 158-174 (1971).

Hill, G. D., and J. W. McGahen, "Further Studies on Soil Relationships of the Substituted Urea Herbicides for Pre-Emergence Weed Control," Proc. South. Weed Control Conf., 8:284-293 (1955).

Hill, G. D., J. W. McGahen, H. M. Baker, D. W. Finnerty, and C. W. Bingeman, "The Fate of Substituted Urea Herbicides in Agricultural Soils," *Agron. J.*, 47:93-104 (1955).

Hiltibran, R. C., "Effects of Some Herbicides on Fertilized Fish Eggs and Fry," *Trans. Am. Fish. Soc.*, 96:414-416 (1967).

Hoffman, C. E., "The Mode of Action of Bromacil and Related Uracils," *Second International Conference of Pesticide Chemistry* (1971) contained in: F. M. Ashton and A. S. Crafts (eds.), *Mode of Action of Herbicides*, John Wiley and Sons, New York (1973).

Holly, K., and H. A. Roberts, "Persistence of Phytotoxic Residues of Triazine Herbicides in Soil " *Weed Res.*, 3:1-10 (1963).

Hurle, K. B., and V. H. Freed, "Effect of Electrolytes on the Solubility of Some 1,3,5-Triazines and Substituted Ureas and Their Adsorption on Soil," *Weed Res.*, 12(1):1-10 (1972).

Isensee, A. R., W. C. Shaw, W. A. Gentner, C. R. Swanson, B. C. Turner, and E. A. Woolson, "Revegetation Following Massive Application of Selected Herbicides," *Weed Sci.*, 21(5):409-412 (1973).

Iman, M., and S. I. Ghabbour, "The Effect of Five Herbicides on the Aquatic Oligochaete, *Branchiura sowerbyi* Bedd," Botyu-Kagaku (Institute of Insect Control, Kyoto Univ., Kyoto, Japan) 31(4):147-148, (1966).

Kaufman, D. D., J. R. Plimmer, J. Iwan, and U. I. Klingebiel, "3,3,4,4'-Tetrachloroazoxybenzene from 3,4-Dichloraniline in Microbial Culture," *J. Agr. Food Chem.*, 20(3):916-919 (1972).

Kaufman, D. D., J. R. Plimmer, and U. I. Klingebiel, "Microbial Oxidation of 4-Chloroaniline," *J. Agr. Food Chem.*, 21(1):127-132 (1973).

Kazarina, E. M., "Translocation of Herbicide Monuron in Soil Depending on Various Factors," *Tr. Vses. Nauch. Issled. Inst. Zashch. Rast.*, 24:36-40 (1965).

Khubutiya, R. A., and A. A. Gigineishvili, "Determination of Residual Amounts of Soil Herbicides in the Soil and Aurantiaceae," *Khim. Sel. Khoz.*, 9(12): 924-928 (1971).

Komarovsky, F. Y., "Experimental Study of the Toxicity of the Complex Preparation Monurox for Fish Under Chronic Experimental Conditions," *Eksp. Vod. Toksikol* 3:17-24 (1972).

Komarovsky, F. Y., and N. A. Popovich, "Toxic Effects in Fish Chronically Exposed to Urea Derivatives," *Eksp. Vod. Toksikol.*, 2:77-91 (1971).

Kuznetsov, M. D., and S. F. Mikhailov, "Residual Action of Herbicides in the First and Second Fields of a Fruit Crop Nursery Used on a Neutral Field," *Primen. Pestits. Sel. Khoz. Mater. Nauch. Konf.*, 59-63 (1969).

Lanzilotta, R. P., and D. Pramer, "Herbicide Transformation. II Studies with an Acylamidase of *Fusarium solani*," *Appl. Microbiol.*, 19(2):307-313 (1970).

Lawrence, J. M., "Aquatic Herbicide Data," *Agricultural Handbook No. 231*, U.S. Department of Agriculture, Superintendent of Documents, U.S. Government Printing Office, Washington, D.C. (December, 1962).

Lichtenstein, E. P., T. T. Liang, and B. N. Angeregg. "Synergism of Insecticides by Herbicides," *Science*, 181:847-849 (1973).

Lopez, C. E., and J. I. Kirkwood, "Growth Patterns of *Fusarium* sp. Under Different Concentration of Two Urea Derivative Herbicides," *Texas Agricultural Experiment Station Progress Report* PR-3132 (1972).

Lopez, C. E., and J. I. Kirkwood, "Isolation of Microorganisms from a Texas Soil Capable of Degrading Urea Derivative Herbicides," *Soil Sci. Soc. Amer. Proc.*, 38(2):309-312 (1974).

Maloney, T. E., "Control of Algae with Chlorophenyl Dimethyl Urea," *J. Am. Water Works Assoc.*, 50:417-422 (1958).

Martin, W. L., and S. C. Wiggans, "The Tolerance of Earthworms to Certain Insecticides, Herbicides, and Fertilizers," *Oklahoma Agr. Exp. Sta., Proc. Ser.* P-334 (1959), Reprinted in D. Pimentel, *Ecological Effects on Nontarget Species*, Executive Office of the President, Office of Science and Technology, Superintendent of Documents, U.S. Government Printing Office, Washington, D.C. (1971)

McClure, G. W., "Accelerated Degradation of Herbicides in Soil by the Application of Microbial Nutrient Broths," *Contrib. Boyce Thompson Inst.*, 24(11):235-240 (1970).

Mikhailov, N. E., "Experimental Basis for Permissible Concentrations of Monuron and Diuron in Reservoir Waters," *Prom Zagryazneniya Vodoemov*, 8:72-84 (1967).

Moyer, J. R., "Some Aspects of Adsorption and Desorption of Herbicides with Soil Colloids," *Diss. Abstr. Int.*, 33(3):981B-982B (1972).

Moyer, J. R., R. B. McKercher, and R. J. Hance, "Desorption of Herbicides from Montmorillonite and Peat," *Can. J. Soil Sci.*, 52(3):439-447 (1972).

Mullison, W. R., "The Significance of Herbicides to Non-Target Organisms," *Proceedings Northeastern Weed Control Conference*, 24:111-147 (1970).

Murray, D. S., W. L. Rieck, and J. Q. Lynd, "Microbial Degradation of Five Substituted Urea Herbicides," *Weed Sci.*, 17(1):52-55 (1969).

Nishiuchi, Y., "Testing Methods for the Toxicity of Agricultural Chemicals to Aquatic Organisms," Japan Pesticide Information, (Japan Plant Protection Association, Tokyo) 19:15-19 (1974).

Otten, R. J., J. E. Dawson, and M. M. Schreiber, "The Effects of Several Herbicides on Nitrification in Soil," Proc. N. E. Weed Cont. Conf., 11:120-129 (1957), Reprinted in D. Pimentel, Ecological Effects of Pesticides on Non-Target Species, Executive Office of the President, Office of Science and Technology, Superintendent of Documents, U.S. Government Printing Office, Washington, D.C. (1971).

Pantera, H., "Effect of Herbicides on Algae in the Soil," Meded. Fac. Landbouwwetensch. Rijksuniv. Gent., 35(2):847-854 (1970).

Pantera, H., "Effect of High Doses of Herbicides on Some Groups of Soil Microorganisms," Pamiet. Pulawski, 51:69-76 (1972).

Pidgaiko, M. L., "Use of Production-Biological Settling Methods in Studying the Toxicity of Pesticides for Zooplankton," Metod. Biol. Issled. Vod. Toksikol., 169-172 (1971).

Pidgaiko, M. L., and E. P. Shcherban, "Development of Zooplankton and Zoobenthos in Reservoirs Treated with Monuron," Vop. Vod. Toksikol., 96-102 (1970).

Pillay, A. R., and Y. T. Tchan, "Soil Algae. VII. Adsorption of Herbicides in Soil and Prediction of Their Rate of Application by Algal Methods," Plant Soil, 36(3):571-594 (1972).

Pimentel, D., Ecological Effects of Pesticides on Nontarget Species, Executive Office of the President, Office of Science and Technology, Superintendent of Documents, U.S. Government Printing Office, Washington, D.C. (1971).

Polyvyannyi, P. M., "Effect of Herbicides on Biological Processes in Soils," Nauk. Pr., Ukr. Sil's'Kogospod. Akad., 24;42-50 (1970).

Pont, V., H. T. Jarczyk, G. F. Collet, and R. Thomas, "Identification and Stability in vitro of Metabolites of 1,3 dimethyl 3-(2-benzothiazolyl)-urea," Phytochem. 13(5):785-792 (1974).

Quastel, J. H., and P. G. Scholefield, "Urethanes and Soil Nitrification," Appl. Microbiol., 1:282-287 (1953), Reprinted in D. Pimentel, Ecological Effects of Pesticides on Nontarget Species, Executive Office of the President, Office of Science and Technology, Superintendent of Documents, U.S. Government Printing Office, Washington, D.C. (1971).

Rhodes, R. C., I. J. Belasco, and H. L. Pease, "Determination of Mobility and Adsorption of Agrichemicals on Soils." J. Agr. Food Chem., 18(3):524-528 (1970).

Rosen, J. D., M. Siewierski, and G. Winnett, "FMN-Sensitized Photolyses of Chloroanilines," J. Agr. Food Chem., 18(3):494-496 (1970).

Shadbolt, C. A., and F. L. Whiting, California Agr., 15(11):10-11 (1961).

Shcherban, E. P., "Effect of Monuron on the Potential Productivity of Some Planktonic Cladocera," Eksp. Vod. Toksikol., 2:92-103 (1971).

Shchetinskaya, L. I., and V. M. Bagnyuk, "Effect of Some Pesticides on the Dehydrogenase Activity of Bacteria," Eksp. Vod. Toksikol., 3:106-118 (1972).

Sheets, T. J., "Review of Disappearance of Substituted Urea Herbicides from Soil," J. Agr. Food Chem., 12(1):303 (1964).

Smith, J. W., and T. J. Sheets, "Uptake, Distribution, and Metabolism of Monuron and Diuron by Several Plants," J. Agr. Food Chem., 15:577-581 (1967).

Spiridonov, Y. Y., and V. I. Kamenskii, "Factors Determining Monuron Stability in Soil," Tr. Vses. Nauch. Issled. Inst. Udobr. Agropochvoved, 51:271-283 (1971).

Spiridonov, Y. Y., V. I. Kamenskii, and A. I. Yakolev, "Reasons for the Rapid Loss of Herbicide Phytotoxicity in Moist Subtropical Soils," Subtrop. Kul't., (2):150-158 (1970).

Spiridonov, Y. Y., V. S. Skhilodze, and G. S. Spiridonova, "Action of Diuron and Monuron in Red Soil of the Moist Subtropics of the Adzhar Assr," Subtrop. Kul't., (3):152-160 (1970).

Spiridonov, Y. Y., V. S. Skhilodze, and G. S. Spiridonova, "Action of Diuron and Monuron in Meadow-Bog Soil of the Moist Subtropics in the Adzhar Assr," Subtrop. Kul't., (1):150-155 (1972).

Springer, P. F., "Effects of Herbicides and Fungicides on Wildlife," North Carolina Pesticide Manual (1957), Reprinted in D. Pimentel, Ecological Effects of Pesticides on Nontarget Species, Executive Office of the President, Office of Science and Technology, Superintendent of Documents, U.S. Government Printing Office, Washington, D.C. (1971).

Still, G. G., "3,4,3'4 Tetrachlorobenzene: Its Translocation and Metabolism in Rice Plants," Weed Res. 9:211-217 (1969).

Swanson, C. R. and H. R. Swanson, "Inhibition of Degradation of Monuron in Cotton Leaf Tissue by Carbamate Insecticides," Weed Sci., 16:481-484, (1968).

Sweetser, P. B., and C. W. Todd, "The Effect of Monuron on Oxygen Liberation in Photosynthesis," Biochim. Biophys. Acta, 51:505-508 (1961).

Sweetser, P. B., "Photoinactivation of Monuron, 3-(p-Chlorophenyl)-1,1-dimethylurea, by Riboflavin 5-Phosphate," Biochim. Biophys. Acta 66:78-85 (1963).

Tulabaev, B. D., "Effect of the Herbicides Simazine, Atrazine, Monuron, Phenuron, and Diuron on the Microflora of Meadow Soil," Nauch. Tr. Samarkand. Sel'skokhoz. Inst., 22:154-159 (1971).

Ukeles, R., "Growth of Pure Cultures of Marine Phytoplankton in the Presence of Toxicants," Appl. Microbiol., 10(6):532-537 (1962).

Upchurch, R. P., J. A. Keaton, and F. L. Selman, "Soil Sterilization Properties of Monuron, Diuron, Simazine, and Isocil," Weed Sci., 16(3):358-364 (1968).

U.S. Department of the Interior, "Water Quality Criteria," Report of the National Technical Advisory Committee, Federal Water Pollution Control Administration (1968).

Van Bladel, R., and A. Moreale, "Adsorption of Fenuron and Monuron (Substituted Ureas) by Two Montmorillonite Clays," Soil Sci. Soc. of Amer. Proc 38(2):244-249 (1974).

van der Drift, J., "Pesticides and Soil Fauna," Meded. Rijksfac. Landbouwwetensch Gent., 35(2):707-716 (1970).

Vandermeulen, J. H., N. D. Davis, and L. Muscatine, "The Effect of Inhibitors of Photosynthesis on Zooxanthellae in Corals and Other Marine Invertebrates," Marine Biol., 16:185-191 (1972).

Vengerskaia, K., and D. A. Kur, "The Determination of Small Quantities of Monuron in Air," Med. Zh. Uzbekistana, 3:65-66 (1969).

Walker, C. R., "Diuron, Fenuron, Monuron, Neburon, and TCA Mixtures as Aquatic Herbicides in Fish Habitats," Weeds, 13:297-301 (1965).

Wallnöfer, P. R., "The Decomposition of Urea Herbicides by Bacillus sphaericus Isolated from Soil," Weed Residue, 9:333-339 (1969).

Wallnöfer, P. R., and J. Bader, "Degradation of Urea Herbicides by Cell Free Extracts of Bacillus sphaericus," Appl. Microbiol., 19:714-717 (1970).

Wallnöfer, P. R., S. Safe, and O. Hutzinger, "Microbial Demethylation and Debutynylation of Four Phenylurea Herbicides," Pest. Biochem. and Physiol., 3:253-258 (1973).

Walsh, G. E., "Effects of Herbicides on Photosynthesis and Growth of Marine Unicellular Algae," Hyacinth Control J., 10:45-58 (1972a).

Walsh, G. E., "Insecticides, Herbicides, and Polychlorinated Biphenyls in Estuaries," J. Washington Acad. Sci., 62(2):122-139 (1972b).

Walsh, G. E., and T. E. Grow, "Depression of Carbohydrate in Marine Algae by Urea Herbicides," Weed Sci., 19(5):568-570 (1971).

Welker, W. V., Jr., and J. L. Brogdon, "Effects of Continued Use of Herbicides in Asparagus Plantings," Weed Sci., 20(5):428-431 (1972).

PART II. INITIAL SCIENTIFIC REVIEW

SUBPART D. PRODUCTION AND USE

CONTENTS

Registered uses of Monuron 92

  Federally Registered Uses. 92
  State Regulations. 93

Production and Domestic Supply 98

  Volume of Production 98
  Imports. 98
  Exports. 98
  Domestic Supply. 99
  Formulations 99

Use Patterns of Monuron in the United States 100

  General. 100
  Agricultural Uses of Monuron 100
  Nonagricultural Uses of Monuron. 100
  Monuron Uses in California 101
  Monuron Usage in Arizona 103

References 106

This section contains information on the registration and on the production and uses of monuron. The section summarizes rather than interprets data reviewed.

Registered Uses of Monuron

Federally Registered Uses - Monuron is a broad-spectrum general herbicide used in the control of many annual and perennial grasses and herbaceous weeds on noncropland areas where bare ground is desired. The degree of control and duration of effect vary with the amount of monuron applied, the soil type, rainfall, and other conditions. Most annual weeds are controlled at lower rates than perennial weeds.

Monuron is registered (U.S. Environmental Protection Agency, 1974) in the United States for nonselective weed control on noncropland areas including utility, highway, pipeline, railroad, and other rights-of-way; petroleum tank farms; lumberyards; storage areas; industrial plant sites; and on irrigation and drainage ditchbanks; 4.0 to 16.0 lb AI/acre are used for the control of most annual and perennial weeds. Additional treatment may be required where a longer period of control is desired, or where deep-rooted, hard-to-kill perennial weeds such as Johnson grass are present. In low rainfall areas, monuron may not satisfactorily control deep-rooted perennial weeds.

For vegetation control on irrigation ditchbanks, monuron should be applied during the noncrop season, when the ditch is not in use, and before expected seasonal rainfall. Following treatment, at least 4 in of rainfall are required to fix monuron in the soil sufficiently so as to avoid injury to crops from irrigation water supplied by monuron-treated ditches. If the rainfall following monuron treatment does not total at least 4 in, it is recommended that the ditch be filled with water allowed to stand for 72 hr. The water must not be used for irrigation, but should be drained off before the ditch is used for irrigation purposes. Monuron should not be used for the treatment of any ditches into which roots of trees or other desirable plants may extend because injury may result.

In the past, monuron was also registered and recommended for selective control of weeds (including barnyard grass (water grass), crabgrass, Colorado grass, foxtail, Johnson grass, pigweed, purslane, Spanish needles, ragweed, chickweed, wild mustard, annual morning glory, and lamb's quarters) and on several crops including asparagus, cotton, sugarcane, pineapple, avocados, and citrus fruits. Tolerances for residues of monuron were established at 7 ppm for asparagus, and 1 ppm for the following crops: avocados; cottonseed; grapes; dry bulb onion; pineapples; spinach; sugarcane; and citrus fruits, including oranges, lemons, limes, grapefruit, kumquats, tangerines, and citron. All of these tolerances were revoked effective July 26, 1973, and monuron is no longer registered or recommended for use on any of these crops.

Monuron is also registered in combination with TCA (trichloroacetic acid), with sodium meta and tetra borates, or with sodium chlorate and metaborate. These products are registered and used for the same weed control purposes as formulations containing only monuron.

In addition, monuron is registered in combination with several other herbicides for the control of weeds in dichondra lawns. Typical products of this kind contain approximately one part of monuron active ingredient per 10 parts active ingredient of the other herbicide component, such as monuron (0.35%) combined with bensulide (4.42%), or monuron (0.383%) combined with diphenamid (3.44%). In a number of dichondra lawn products, these herbicide combinations have been combined with fertilizers, minor elements, and/or insecticides.

For more details on the registered uses of monuron, including general and specific use directions, precautions, limitations of use, and other details, see Table 10, which presents a commercial label of the most frequently used monuron formulation (80% wettable powder). The label contains selective crop uses cancelled in 1973, with a notation of cancellation. In the past, uses on crops contributed significantly to the total quantities of monuron used. Table 11 presents a representative use of monuron.

State Regulations - In a number of states, the sale and use of pesticides are subject to State pesticide laws and regulations, in addition to Federal statutes. For instance, in California, 42 specific pesticides have been designated as "injurious or restricted materials." The use of pesticides in this category is subject to special restrictions under regulations administered by the California State Department of Agriculture. Monuron has not been designated as an "injurious or restricted" pesticide in California.

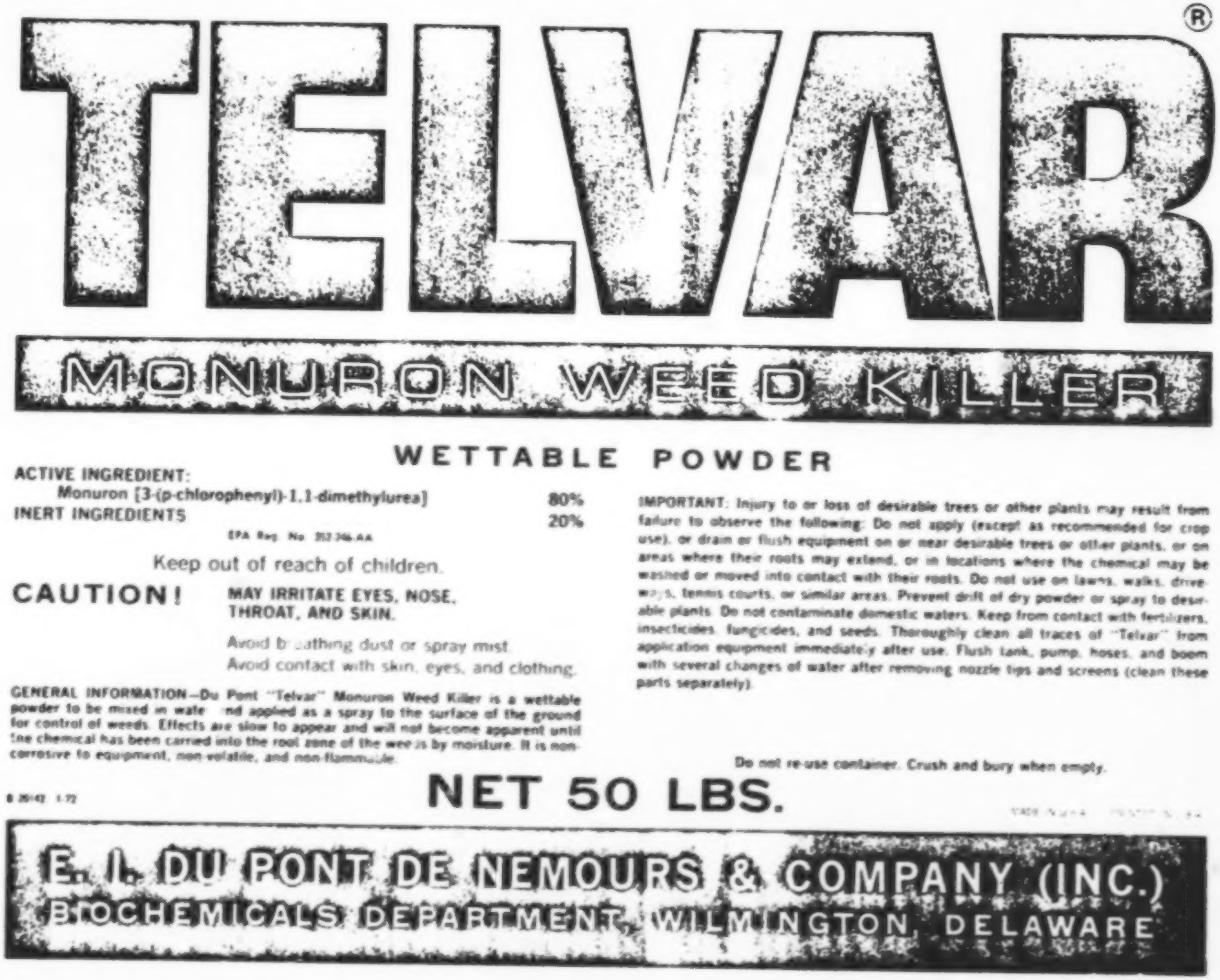
Table 11. MONURON NONCROP USAGE

Use	Tolerance (ppm)	Dosage lb AI*/acre	Limitations
Irrigation and drainage ditches	extended	80	Apply during noncrop season when ditch is not in use. Waste first water after treatment before irrigating crops.

*AI = active ingredient

Source: U.S. Environmental Protection Agency, EPA Compendium of Registered Pesticides, Vol. I (1974).

Table 12. MONURON 80% WETTABLE POWDER SPECIMEN LABEL



TELVAR®

MONURON WEED KILLER

WETTABLE POWDER

ACTIVE INGREDIENT:	
Monuron [3-(p-chlorophenyl)-1,1-dimethylurea]	**80%**
INERT INGREDIENTS	**20%**

EPA Reg. No. 352-246-AA

Keep out of reach of children.

CAUTION! **MAY IRRITATE EYES, NOSE, THROAT, AND SKIN.**

Avoid breathing dust or spray mist.
Avoid contact with skin, eyes, and clothing.

GENERAL INFORMATION—Du Pont "Telvar" Monuron Weed Killer is a wettable powder to be mixed in water and applied as a spray to the surface of the ground for control of weeds. Effects are slow to appear and will not become apparent until the chemical has been carried into the root zone of the weeds by moisture. It is non-corrosive to equipment, non-volatile, and non-flammable.

IMPORTANT: Injury to or loss of desirable trees or other plants may result from failure to observe the following: Do not apply (except as recommended for crop use), or drain or flush equipment on or near desirable trees or other plants, or on areas where their roots may extend, or in locations where the chemical may be washed or moved into contact with their roots. Do not use on lawns, walks, driveways, tennis courts, or similar areas. Prevent drift of dry powder or spray to desirable plants. Do not contaminate domestic waters. Keep from contact with fertilizers, insecticides, fungicides, and seeds. Thoroughly clean all traces of "Telvar" from application equipment immediately after use. Flush tank, pump, hoses, and boom with several changes of water after removing nozzle tips and screens (clean these parts separately).

Do not re-use container. Crush and bury when empty.

B 20142 1-72

NET 50 LBS.

E. I. DU PONT DE NEMOURS & COMPANY (INC.)
BIOCHEMICALS DEPARTMENT, WILMINGTON, DELAWARE

Table 12. (continued)

DIRECTIONS

Use a fixed boom power sprayer properly calibrated to a constant speed and rate of delivery. For details on spray equipment and calibration, see Du Pont booklet "Instructions for Applying Du Pont Weed Killers for Selective Weed Control in Crops". Use sufficient water (min. 40 gals. per acre for non-cropland, 25 to 40 gals. per acre for crops) to provide thorough and uniform coverage of the ground. Spray booms must be shut off while starting, turning, slowing or stopping, or injury to the crop may result. Continuous agitation in the spray tank is required to keep the material in suspension.

When a range of dosage rates is listed, use the lower rates on lighter soils (sandy loams, loams, and soils low in organic matter) and the higher rates on heavier soils (clay loams, clays, and soils high in organic matter).

NON-CROP WEED CONTROL

"Telvar" is an effective general herbicide for the control of many annual and perennial grasses and herbaceous weeds on non-cropland areas where bare ground is desired. The degree of control and duration of effect will vary with the amount of chemical applied, soil type, rainfall, and other conditions.

"Telvar" may be used at any time for non-cropland weed control, except when ground is frozen, provided adequate moisture is supplied by rainfall or artificial means to activate the chemical. Best results are obtained if applied shortly before weed growth begins. If dense growth is present, remove tops and spray the ground.

GENERAL WEED CONTROL: To control most weeds for an extended period of time on non-cropland such as UTILITY, HIGHWAY, PIPELINE and RAILROAD RIGHT OF WAYS, PETROLEUM TANK FARMS, LUMBER-YARDS, STORAGE AREAS, INDUSTRIAL PLANT SITES, and AROUND FARM BUILDINGS—Apply 5 to 20 lbs. of "Telvar" per acre to control most annual weeds. Use 20 to 60 lbs. per acre for perennial weeds; additional treatment may be required where a longer period of control is desired or when hard-to-kill, deep-rooted perennial weeds such as Johnsongrass are present. In low rainfall areas, "Telvar" may not provide satisfactory control of deep-rooted perennial weeds.

IRRIGATION AND DRAINAGE DITCHES: Apply 5 to 20 lbs. per acre to control most annual weeds; use 20 to 60 lbs. per acre to control both annual and perennial weeds. For irrigation ditches, apply during the non-crop season, and when ditch is not in use. To minimize movement of "Telvar" with irrigation water (to avoid possible crop injury), it is essential that the herbicide be fixed in the soil by moisture. Apply before expected seasonal rainfall (if possible when soil in the ditch is still moist). Following treatment, if rainfall has not totaled at least 4 inches, fill ditch with water and allow to stand for 72 hours; drain off and waste remaining water before using ditch. Do not treat any ditch into which roots of trees or other desirable plants may extend as injury may result.

FOR SMALL AREAS: One-half cupful of "Telvar" per 100 sq. ft. is approximately 50 lbs. per acre. A hand sprayer or sprinkling can may be used for application; shake or stir frequently.

SELECTIVE USE IN CROPS

> "Telvar" should be used only in accordance with recommendations on this label, or in separate published Du Pont recommendations available through local dealers.

"Telvar" selectively controls weed seedlings such as barnyardgrass (watergrass), crabgrass, Coloradograss, foxtail, Johnsongrass, pigweed, purslane, Spanishneedles, ragweed, chickweed, wild mustard, annual morningglory, and lambsquarters. Results vary with soil types (the lower rates are effective on the lighter soils and the higher rates on heavier soils) and environmental conditions. Moisture is necessary to activate the chemical; best results are obtained if moisture is supplied by rainfall or irrigation within two weeks after application. Soil should be well prepared and as free as possible from trash and clods; any well established weeds should be eliminated by mechanical or other means. Unless otherwise directed, surface of the soil should not be cultivated or disturbed after application of "Telvar" as efficiency may be reduced.

IMPORTANT—Unless otherwise directed, do not replant treated areas to any crop within two years after last application as injury to subsequent crops may result.

ASPARAGUS: Do not apply to newly seeded asparagus nor to young plants during the first growing season after setting nor on plants with exposed roots as severe injury may result. Apply as a band or broadcast treatment. On light, sandy soils and other soils low in clay or organic matter, apply 1 to 2 lbs. per acre (for band application, use proportionately less). On soils high in clay or organic matter, use 2 to 4 lbs. per acre. Two applications may be used, the first application should be made before weeds become established but no earlier than 4 weeks before spear emergence and no later than the early cutting period (if weeds are controlled into the cutting period by cultural practices, application may be delayed until immediately after the last cultivation); a second application may be made immediately following completion of harvest provided rainfall is expected. When two applications are used in one season, do not exceed 3 lbs. per acre per application. In Washington (irrigated crop), apply only a single treatment of 4 lbs. per acre in late November or December.

ORANGES, LEMONS, AND AVOCADOS—California (except Imperial and Coachella Valleys): Use only under trees established in the grove for at least one year. Apply as a directed spray avoiding contact of foliage and fruit with spray or drift. Do not apply under citrus trees that have been subjected to freezing within 6 months; do not apply in home plantings of citrus or in areas where the roots of other valuable plants or trees may extend; do not use on light (sand, loamy sand or gravelly) soils nor where organic matter is less than 1% as injury may result.

Make a single application of 3 to 4 lbs. per acre as a broadcast spray shortly after grove has been laid-up in final form (non-tillage program) in late fall or early winter. As an alternative, apply 2 lbs. per acre in October or November, and repeat at the same rate in March or April. Subsequent annual applications of 2 to 3 lbs. will usually give adequate weed control.

COTTON—Preemergence (except Arizona and California): Make a single application as a broadcast or band spray after planting but before cotton emerges. Use at the following rates:

Table 12. (continued)

Broadcast Treatment Soil Type*	Lbs. "Telvar" Per Acre (in 25 to 40 Gals. Water)	Lbs. Monuron Applied/Acre
Clay—low organic matter	1.25	1.0
Clay—moderate organic matter	1.6	1.3
Clay—high organic matter	2.0	1.6

*Use only on heavy (clay) soils. For other soil types, use "Karmex" Diuron Weed Killer.

Band Treatment: Use proportionately less, for example, for 14" band on 42" row, use ⅓ of the broadcast rate. Apply immediately after cotton is planted; wherever possible, planting and spraying should be combined in one operation. For best results, soil should be well prepared and as free as possible from trash and clods. Shallow incorporation (no deeper than ¼") with a rotary hoe or similar equipment following planting usually improves results particularly during dry weather. A wide press wheel following planting should be used to provide a level seed bed for subsequent early season postemergence treatments.

Treatment usually provides weed control for a period of 3 to 8 weeks. Sufficient moisture (usually 1" to 2") in the form of rainfall or irrigation is necessary after treatment to carry the chemical into the root zone of germinating weeds; best results are obtained when this occurs within 2 weeks after application. If moisture is insufficient to activate "Telvar" or if soil becomes crusted before crop emerges, a shallow rotary hoeing (no deeper than ¼") should be made before weeds become well established.

If initial seeding fails to produce a stand, cotton may be replanted in soil treated with "Telvar". Wherever possible, avoid disturbing original bed. If necessary to rework soil before replanting, use shallow cultivation such as discing; do not re-list nor move soil into the original drill area; plant seed at least 1 inch deep; do not retreat field with a second preemergence application of "Telvar" during the same crop year as injury to the crop may result.

Note: Use of "Telvar" in conjunction with systemic phosphate insecticides (applied as seed treatment or as soil treatment at planting) is NOT recommended as injury to cotton may result.

Late Season (Lay-By)—Arizona and California; other areas on heavy soils only: Use 1 to 1½ lbs. per acre. Do not use on light (sand, loamy sand) soils nor where organic matter is less than 1% as injury to cotton may result. Direct spray to cover the soil beneath cotton plants and between rows, keeping contact with crop plants at a minimum. DO NOT SPRAY OVER TOP OF COTTON. Apply immediately after the last cultivation, but not before the cotton has reached a height of at least 20 inches. In irrigated cotton, best weed control is obtained if the field is irrigated within 3 to 4 days after application; thoroughly wet the surface of the ground over the row to carry the chemical into the root zone of germinating weeds.

Subsequent Crops:

"Telvar"—Type of Application	Crops That May Follow Treated Cotton
Band preemergence	Any crop 4 months after application.
Broadcast preemergence	Cotton, soybeans, corn or grain sorghums (not sorgos or forage sorghums nor grass sorghums) the next spring. Do not replant treated areas to any other crop within one year after last application as injury to subsequent crops may result.
Lay-by only -or- Preemergence plus lay-by	Cotton, corn, grain sorghums (not sorgos or forage sorghums nor grass sorghums) the next spring. Do not replant treated areas to any other crop within one year after last application as injury to subsequent crops may result.

Note: During a single crop season, do not exceed 2.2 lbs. monuron per acre as injury to subsequent crops may result.

PINEAPPLE—Hawaii: Apply 4 to 8 lbs. per acre as a broadcast spray immediately after planting and prior to weed emergence. Use 4 lbs. after harvesting plant crop (for ratoon crop). For plant crop only, a second and third broadcast or interspace application may be made prior to differentiation at the rate of 2 lbs. per acre at intervals of not less than 2 months. Additional applications to plant crop may be made as needed to interspace only, using 2 lbs. per acre. Do not apply more than 3 broadcast sprays (maximum 12 lbs. per acre) prior to differentiation nor more than 16 lbs. total per acre per plant crop. Treated areas may be planted to pineapple or sugar cane one year after last application.

SUGAR CANE: To prevent possible crop injury on new cane varieties, tolerance to "Telvar" should be determined prior to adoption as field practice. Do not treat sugar cane growing on thinly covered sub soils or rocky areas; do not use on light (sand, loamy sand or gravelly) soils nor where organic matter is less than 1% as injury to cane may result. Temporary chlorosis of the crop may result from application over emerged cane; to minimize chlorosis, use directed postemergence sprays. The following rates are for broadcast treatment; for band application, use ⅓ of broadcast rate when treating ⅓ of the area.

Florida: For high organic soils, apply 2 to 4 lbs. per acre prior to weed emergence after planting or after harvesting plant crop (for ratoon crop). A second and third application of 2 lbs. per acre may be made as needed by directed spray inter-row. Do not apply more than 3 treatments nor more than 6 lbs. total per acre between planting (or ratooning) and harvest.

Hawaii and Puerto Rico: Apply 4 to 6 lbs. per acre prior to weed emergence after planting or after harvesting plant crop (for ratoon crop). A second and third application of 2 to 3 lbs. per acre may be made as a broadcast spray over emerged cane or by directed spray inter-row. Do not apply more than 3 treatments nor more than 10 lbs. total per acre between planting (or ratooning) and harvest. Treated areas may be planted to sugar cane or pineapple one year after last application.

Louisiana: Use on plant cane seeded on fallowed ground. Apply 3 to 3¾ lbs. per acre either in the fall (August through October) or spring (January through April) before weeds or cane emerge.

NOTICE TO BUYER—Seller warrants that this product conforms to the chemical description on the label thereof and is reasonably fit for purposes stated on such label only when used in accordance with directions under normal use conditions. This warranty does not extend to use of this product contrary to label use directions, or under abnormal use conditions, or under conditions not reasonably foreseeable to seller; buyer assumes all risk of any such use. Seller makes no other warranties, express or implied.

Table 12. (continued)

TELVAR® MONURON WEED KILLER

EPA REG. NO. 352-246

CROPS: "Telvar" is no longer registered for use in crops; use only for non-crop weed control.

NON-CROP WEED CONTROL: Use in accordance with directions on product label.

B-21094 2-73

Production and Domestic Supply

Volume of Production - Reports issued by the U.S. Tariff Commission (1970, 1971, 1972, 1973), list only one basic producer of monuron in the United States in the 1970 to 1973 period, E. I. du Pont de Nemours and Company. The *Farm Chemicals Handbook* (1974) reports that monuron is produced abroad by Makhteshim-Agan Chemical Manufacturers Limited, Ashdod, Israel.

Monuron-TCA combination products are produced by Allied Chemical Corporation.

The TC reports do not individually report the production and sales volumes of monuron. Monuron is included in the category "Pesticides and Related Products, Cyclic," in a classification entitled "All Other Cyclic Herbicides and Plant Hormones. The total production volume (as active ingredient) for this classification was: 231,021,000 lb in 1970, 358,433,000 lb in 1971, 344,789,000 lb in 1972, and 357,310,000 lb in 1973.

Compared to the major herbicides in this classification, the production and sales volumes of monuron are too small for TC data to be of value in making quantitative estimates on monuron.

The U.S. Department of Agriculture (1968, 1970, 1974) conducted surveys on the quantities of pesticides used by U.S. farmers in 1964, 1966, and 1971. In these reports, monuron is shown individually only in the 1964 survey. According to this source, a total of 231,000 lb of monuron AI were used on farm crops in 1964 in the United States. In the 1966 and 1971 USDA surveys, monuron was included in a category entitled "Other Phenyl Urea Herbicides." Since the USDA reports cover only agricultural uses of pesticides, production and use volumes of monuron (since the 1973 revocation of uses on crops) are not obtainable from this source.

According to RvR Consultants estimates, the volume of production of monuron in the United States in 1973 was less than 1 million lb AI, probably ranging between 500,000 to 900,000 lb. Somewhat larger quantities of monuron are believed to have been produced in past years when monuron was registered for crop uses and had less competition from more recently developed phenyl urea and other organic herbicides.

Imports - TC reports on benzenoid chemicals for 1972 and 1973 list the following figures for imports of monuron active ingredient into the United States: 35,000 lb, 1971; 111,800 lb, 1972; 142,138 lb, 1973.

Exports - Monuron is not listed separately in Bureau of Census commodity descriptions on herbicide exports. Total exports in 1972 for technical herbicidal preparations were placed at 38,967,237 lb. Based on other sources, Midwest Research Institute (MRI) estimates that the export volume of monuron in 1972 and 1973 amounted to about 100,000 lb AI/yr.

Domestic Supply - MRI estimates of the 1973 domestic supply of monuron are: U.S. production, 500,000 to 900,000 lb; imports, 150,000 lb; exports, 100,000 lb; domestic supply, 550,000 to 950,000 lb.

Indications are that domestic production volume and quantities of monuron used are on the decline. This is partially attributed to the fact that all uses of monuron on agricultural crops have been discontinued and the residue tolerances covering these uses have been revoked. In addition, a number of more recently developed phenyl urea and other herbicides are replacing monuron's noncrop uses.

Formulations - Monuron is available to users in the United States in several different concentrations and formulations, offered by about a dozen different suppliers.

The most widely used monuron formulation is an 80% wettable powder. Suppliers of monuron in this form include du Pont, Aceto Chemical Company, and Allied Chemical Corporation.

Several monuron granular formulations are available, including one containing 8% active ingredient, offered by Horne-Boatright Chemical Company (Minneapolis, Minnesota) and one containing 3.2% active ingredient, offered by Ralston Purina Company (St. Louis, Missouri).

Several formulators offer granular formulations in which low concentrations of monuron (generally 2.4 to 4.0%) are combined with sodium metaborate, sodium tetraborate and/or sodium chlorate. Suppliers of such formulations include Crown Chemicals (St. Louis, Missouri) and Chipman Chemical, Limited (London, Ontario).

Several formulations containing monuron-TCA (trichloroacetic acid) as active ingredient are available, including granulars containing 5.5, 11, and 22% of combined active ingredient, and a liquid-oil concentrate containing 32.4% of active ingredient. The principal supplier of these monuron-TCA products which are offered under the trade name "Urox" is Allied Chemical Corporation, Union Texas Petroleum Division, Agricultural Department, Houston, Texas.

Suppliers of dichondra lawn herbicides containing monuron include the Kelly Western Seed Division of the Pax Company, and the Pax Company, both at Salt Lake City, Utah, and the Occidental Chemical Company, Lathrop, California.

Monuron technical (probably primarily from overseas production) is offered by at least 2 suppliers, Aceto Chemical Company, Inc. (Flushing, New York) and Chempar Chemical Company, Inc. (New York City).

In the past, a liquid suspension formulation of monuron containing 28% active ingredient (2.8 lb AI/gal) was available under the trade name "Telvar ML" from du Pont. The formulation is no longer produced.

There are no dusts or pressurized formulations of monuron available.

Use Patterns of Monuron in the United States

General - Monuron is a broad spectrum, soil-applied herbicide. It controls susceptible weed seedlings and is absorbed through the roots and translocated upwards in the transpiration system. Uptake through stems or leaves is also possible, but occurs to a much lesser extent. Like all substituted phenyl urea herbicides, monuron is a strong inhibitor of the Hill reaction (the evolution of oxygen in the presence of chloroplasts) and thus of photosynthesis. The herbicidal action of monuron and of other substituted phenyl urea herbicides is believed to be due in part to the buildup of a substance which is toxic to the oxygen-liberating pathway in photosynthesis (Ashton and Crafts, 1973).

In the 1950's and 1960's, monuron was used as a selective herbicide on a few crops, including cotton, sugarcane, asparagus, dry bulb onions, pineapple, and as a directed spray in citrus and avocado groves. All crop uses were discontinued in 1973.

As a nonselective herbicide, monuron has been, and continues to be used for total vegetation control on noncropland areas such as utility, highway, pipeline, railroad, and other rights-of-way, petroleum tank farms, lumberyards, and other industrial storage areas and plant sites, around farm buildings, and on irrigation and draining ditchbanks while the ditches are not in use.

Agricultural Uses of Monuron - In a survey by the U.S. Department of Agriculture (1968) on the quantities of pesticides used by farmers in 1964, monuron uses were cited. At the time monuron outranked all other farm crop herbicides. Out of a total of 329,000 lb AI of phenyl herbicide use reported for 1964, 231,000 lb AI was for monuron, including 80,000 lb for cotton and 147,000 for fruit and vegetable crops. In 1966 and 1971 surveys, monuron was not listed separately, but included in the category "Other Phenyl Urea Herbicides." The total reported use for these herbicides was 644,000 lb AI in 1966 declining to 259,000 lb AI in 1971. Based on other sources, MRI estimates that 180,000 lb of monuron was used on farm crops in 1966 and about 125,000 lb in 1971. Use of monuron is expected to decline further as a result of the 1973 revocation of monuron tolerances and registrations for use on all agricultural crops.

Nonagricultural Uses of Monuron - For nonselective, general vegetation control, monuron is registered for use on noncropland such as rights-of-way, industrial plant sites and storage areas. Monuron users in these non agricultural areas include Federal, state, county, city, and other governmental agencies; irrigation, flood control, vector control, and water resource districts; and industrial and commercial organizations. There may be some uses of monuron on or around private residential properties, although the total quantities appear to be negligible. Small quantities of monuron are used in combination with other herbicides (typically at the ratio of one part of monuron to 10 parts of the other herbicide component), and with fertilizers, minor elements and/or insecticides for dichondra lawns.

Table 13 summarizes the estimated uses of monuron in the United States by major use categories in 1973, assuming 2 different levels of use, 600,000 lb (Case A) and 800,000 lb (Case B).

Table 13. ESTIMATED USES OF MONURON IN THE U.S. BY USE CATEGORIES, 1973

Category	Case A[a]	Case B[b]
	Pounds of active ingredient	
Agriculture	100,000	125,000
Industrial/commercial	400,000	550,000
Government agencies	100,000	125,000
Home and garden	Small	Small
Totals	600,000	800,000

[a] Case A: Assuming total U.S. use = 600,000 lb.
[b] Case B: Assuming total U.S. use = 800,000 lb.

Source: RvR Consultants, Shawnee Mission, Kansas, estimates.

As pointed out, the total U.S. supply of monuron in 1973 ranged between 550,000 and 950,000 lb AI. Use volumes assumed in Case A and Case B, respectively, appear to be realistic.

According to Table 13, industrial and commercial uses accounted for 60 to 70% of the total domestic use of monuron in 1973. The quantities of monuron used by governmental agencies (including all levels of government) in 1973 are about equal to the quantities used on crops, and these 2 use categories combined account for the remaining 30 to 40% of the total estimated domestic consumption of monuron.

Monuron Uses in California - California keeps detailed records of pesticide uses by crops and commodities. The reports are published quarterly and summarized annually. Table 14 summarizes the uses of monuron in California, by major crops and other uses for the 1970 to 1973 period.

Table 14. MONURON[a] USES IN CALIFORNIA BY MAJOR CROPS AND OTHER USES, 1970 TO 1973

Crop/Use	Year			
	1973	1972	1971	1970
	Pounds of active ingredient			
Asparagus	4,420	8,502	4,578	5,680
Cotton	1,492	965	456	215
Citrus	2,969	7,968	1,168	3,276
Avocado	123	1,681	278	28
Other crops[b]	56	-	-	319
All other uses[c]	12,494	14,767	7,703	12,244
Total, all uses	21,554	33,883	14,183	21,762

---

[a] Include small quantities of monuron-TCA.

[b] Include alfalfa, oats, several minor uses on other crops, and use on fallow (open) ground.

[c] Include Federal, state, county, city, and other agencies; irrigation, flood control, vector control districts; the University of California; and uses on or around industrial, residential, turf, water, and other nonagricultural areas.

Source: California Department of Agriculture, Pesticide use reports for 1970, 1971, 1972, and 1973.

In California, monuron is not subject to the special restrictions and reporting requirements imposed upon the sale and use of pesticides designated as "injurious or restricted materials." For this reason, the percentage of all monuron uses reported to the California State Department of Agriculture and included in its statistics is probably not as high as in the case of restricted use pesticides.

According to the reports, the quantities of monuron (including small quantities of monuron-TCA) used in California for all purposes ranged from 14,183 lb AI in 1971 to 33,883 lb AI in 1972. Quantities used in 1970 (21,762 lb AI) and in 1973 (21,554 lb AI) were intermediate.

More monuron was used in California on asparagus than on any other single crop. Citrus fruits were next in line, followed by cotton and avocado. In each of the 4 yr covered in Table 14, larger quantities of monuron were used for nonagricultural purposes in California as compared to farm uses. Nonfarm uses of monuron varied from 7,703 lb AI in 1971 to 14,767 lb AI in 1972, with monuron volumes used in this category in 1970 (12,244 lb AI) and 1973 (12,494 lb AI) ranging in between.

The data summarized in Table 14 does not indicate any clear trend in total use, nor in any of the major crop and other use categories shown individually.

It appears that the California statistics include only a fraction, of the total quantity of monuron actually used in the state since pesticides whose use is not restricted are often applied by private interests to their own land, or used for nonagricultural purposes.

Tables 15 and 16 present the uses of monuron in California in detail, by crops and other uses, number of applications, pounds of active ingredient, and number of acres treated for 1972 and 1973, the two most recent years for which such data are available. These tables expand and provide further insight into the monuron uses in California in 1972 and 1973 included in summary form in Table 14.

Monuron Usage in Arizona

Total agricultural volume data from Arizona on crop and noncrop usage was reported by Ware et al. (1974). In the late 1960's, monuron usage ranged from 12,500 to 17,800 lb. A downward trend in volume appeared in the early 1970's; 15,800 lb in 1971 and 3,000 lb in 1973.

Table 15. USE OF MONURON (INCLUDING MONURON-TCA) IN CALIFORNIA IN 1972 BY CROPS AND OTHER USES, APPLICATIONS, QUANTITIES, AND ACRES TREATED*

Chemical/Commodity	Applications	Pounds	Acres
Monuron TCA, Urox			
City agency		0.51	
Irrigation district		1.53	
Nonagricultural areas	1	371.52	9.00
Other agencies		40.40	
School district		119.27	
Water resources		4.59	
TOTAL	1	537.82	9.00
Monuron			
Asparagus	67	8,502.35	3,597.50
Avocado	21	1,681.17	575.50
Citrus	15	470.22	230.50
City agency		13.28	
Cotton	18	964.98	1,113.00
County Agricultural Commissioner		8.10	
County or city parks		145.33	
County roads		700.40	
Federal agency		3,170.84	
Flood control		928.00	
Grape	2		23.50
Irrigation district		0.06	
Lemon	85	6,530.56	2,839.00
Lettuce/head	2		29.00
Nonagricultural areas	9	106.02	9.75
Orange	53	966.94	958.00
Other agencies		1,901.77	
Residential control		445.15	
School district		269.18	
State highway		62.40	
Structural control		28.80	
Turf	6	6,348.89	517.00
University of California		52.28	
Vector control		48.00	
Water areas	1	0.15	5.00
TOTAL	279	33,344.87	9,897.75

*Disparities in usage in relation to recommended rates may result from data from incomplete reports for number of applications, poundage, or acreage.

Source: California Department of Agriculture, Pesticide Use Report 1972 (1972).

Table 16. USE OF MONURON (INCLUDING MONURON-TCA) IN CALIFORNIA IN 1973 BY CROPS AND OTHER USES, APPLICATIONS, QUANTITIES, AND ACRES TREATED*

Chemical/Commodity	Applications	Pounds	Acres
Monuron TCA, Urox			
City agency		23.04	
Other agencies		12.28	
Residential control		20.28	
School district		49.05	
Water resources		2.23	
TOTAL		106.88	
Monuron			
Alfalfa	7	7.99	558.00
Asparagus	42	4,420.00	2,394.00
Avocado	7	122.74	66.25
City agency		19.74	
Cotton	22	1,491.58	1,062.00
County Agricultural Commissioner		21.19	
County or city parks		171.23	
County road		206.90	
Federal agency		7,760.56	
Fallow (open ground)	1	48.00	3.00
Flood control		583.20	
Grapefruit	1	3.20	40.00
Irrigation district		4.80	
Lemon	35	2,577.71	1,057.50
Nonagricultural areas	3	46.40	5.00
Oats	1	0.23	58.00
Orange	24	387.81	294.00
Other agencies		944.77	
Residential control		815.94	
School district		171.59	
State highway		9.60	
Structural control		32.00	
Turf	8	1,498.40	609.00
University of California		81.60	
Vector control		20.00	
TOTAL	151	21,446.91	6,146.75

*Disparities in usage in relation to recommended use rates may result from data from incomplete reports for number of applications, poundage, or acreage.

Source: California Department of Agriculture, Pesticide Use Report 1973 (1973).

References

Ashton, F. M., and A. S. Crafts, Mode of Action of Herbicides, John Wiley and Sons, New York (1973).

California Department of Agriculture, Pesticide Use Reports for 1970, 1971, 1972, and 1973.

Farm Chemicals Handbook, Meister Publishing Company, Willoughby, Ohio (1974).

U.S. Bureau of the Census, U.S. Exports, Schedule B, Commodity by Country, FT 410 (1972).

U.S. Department of Agriculture. Quantities of Pesticides Used by Farmers in 1964, Agricultural Economic Report No. 131, Economic Research Service (1968).

U.S. Department of Agriculture, Quantities of Pesticides Used by Farmers in 1966, Agricultural Economic Report No. 179, Economic Research Service (1970).

U.S. Department of Agriculture, Farmer's Use of Pesticides in 1971 . . . Quantities, Agricultural Economic Report No. 252, Economic Research Service (1974).

U.S. Environmental Protection Agency, EPA Compendium of Registered Pesticides, Vol. I (1974).

U.S. Tariff Commission, Imports of Benzenoid Chemicals and Products, 1972, TC Publication 601 (1973).

U.S. Tariff Commission, Imports of Benzenoid Chemicals and Products, 1974, TC Publication 688 (1974).

U.S. Tariff Commission, Synthetic Organic Chemicals, U.S. Production and Sales (1970, 1971, 1972, 1973).

Ware, G. W., C. H. Kreader, and L. Moore, "Agricultural Use of Pesticides in Arizona," Progressive Agriculture in Arizona, 26 (4):12-16, College of Agriculture, University of Arizona, Tucson (1974).

PART III. MINIECONOMIC REVIEW

CONTENTS

Page

Introduction 108

Efficacy of Noncrop Control 109

  Effect on Nonselective Weeds 109
  Effect on Specific Grasses 111
  Effect on Woody Plants 111

Economic Benefits of Weed and Grass Control 111

References 113

This section contains a general assessment of the efficacy and cost effectiveness of monuron. Data on the production of monuron in the United States, as well as an analysis of its use patterns at the regional level and by major application, were developed as part of the Scientific Review (Part II) of this report. The section summarizes rather than interprets data reviewed.

Introduction

The efficacy and cost effectiveness of a specific pesticide should be measurable in terms of the increased yield or improved quality of a treated crop which would result in a greater income or lower cost than would be achieved if the pesticide had not been used. Thus, one should be able to pick an isolated test plot of a selected crop, treat it with a pesticide, and compare its yield with that of a nearby untreated test plot. The difference in yield should be the increase due to the use of the pesticide. The increased income (for example, the yield increase multiplied by the selling price of the commodity) less the additional cost (i.e., the pesticide, its application, and the harvesting of the increased yield) is the economic benefit due to the use of the pesticide.

Unfortunately, this method has many limitations. The data derived is incomplete and should be examined with caution. Midwest Research Institute's review of the literature and EPA registration files revealed that experimental tests comparing crops treated with specific pesticides to the same crop without treatment are conducted by many of the state agricultural experimental stations. Only a few of these, however, have attempted to measure increased yield and most of this effort has been directed toward just a few crops such as cotton, potatoes, and sorghum. Most other crop tests measure the amount of reduction in pest levels which cannot be directly related to yield.

Even the test plot yield data are marginally reliable since these tests are conducted under actual field conditions that may never be duplicated again and are often not representative of actual field use. Thus, yield is affected by rainfall, fertilizer use, severe weather conditions, soil type, region of the country, pesticide infestation levels, and the rate, frequency, and method of pesticide application.

Because of these factors, yield tests at different locations and in different years will show a wide variance ranging from a yield decline to significant increases.

The use of market price to estimate the value received by the producer also has its limitations. If the use of the pesticide increases the yield of a crop and the national production is increased, then the market price should decline. According to J. C. Headley and J. N. Lewis (1967), a 1% increase in quantity marketed has at times resulted in a greater than 1% decrease in price. Thus, the marginal revenue from the increased yield would be a better measure of the value received.

A third limitation to the quantification of the economic costs and benefits is the limited availability of data on the quantities of the pesticide used by crop, or pest, the acres treated, and the number of applications. In most cases the amount of monuron used on each crop application is not available.

As a result of these limitations, an overall economic benefit by crop or pest cannot be determined. Where applicable a range of the potential economic benefits derived from the use of the pesticide for control of a specific pest on a specific crop is developed. This economic benefit or loss is measured in dollars per acre for the highest and lowest yield developed from experimental tests conducted by the pesticide producers and the state agricultural experimental stations. The high and low yield increases are multiplied by the price of the crop and reduced by the cost of the pesticide and its application to generate the economic benefit range in dollars per acre.

Economic benefits from noncrop applications (for example, grass and brush control along highways, utility lines, and railroads) are best measured by an alternative costing method. Alternative methods to chemical control include mechanical control such as mowing, discing, bulldozing, and the use of brush-cutting machines. Hand labor is often required for mowing around trees, poles, and other objects, and for weeding or cutting brush. In some cases, burning for control of grasses along canal banks is an alternative.

The true economic benefits cannot be measured because much of the noncrop weed control is for aesthetic reasons such as beautification of highways. It is also a form of preventive maintenance to keep fires from causing damage when grasses are dry. Therefore, the cost of the chemical control should be subtracted from the alternative control cost, such as hand labor or mechanical control, to determine the economic benefit from the use of monuron.

Efficacy of Noncrop Control

Effect on Nonselective Weeds - Monuron is currently registered for nonselective control (semi-soil sterilization) of weeds and grasses along highway rights-of-way, canal banks, railroads, utility lines, and localized weed and grass problems.

In studies on control of weeds under guardrails along highways, Rogerson et al. (1966) conducted experiments in 1963 and 1964 to evaluate the effectiveness of several herbicides. Monuron (as the 80% wettable powder) at a rate of 20 lb/acre controlled mixed broadleaved weeds at 3 separate locations. Control ranged from 73 to 99% 4 months after treatment.

Aldred (1968) reported on tests conducted by the Tennessee Valley Authority to determine the effectiveness of several soil sterilants on grass and woody plants. Monuron was applied at 54 lb/acre in 1966 and resulted in a 75% rate of kill. Species remaining in 1967 included maypop, plantain, blackberry, broomsedge, cudweed, box elder, and panicum.

Sigler (1961) evaluated monuron for control of weeds along railroads and for industrial applications. Tests, comparing several soil sterilants, were conducted in 1957 by the Tennessee Agriculture Experiment Station at Knoxville, Tennessee. The dominant vegetation included: broomsedge, crownbeard, Bermuda grass, common blackberry, Kentucky bluegrass, goldenrod, and tall red tops. Within 10 days after treatment with a 50 lb/acre dosage monuron apparently killed the vegetation. Monuron did not kill as rapidly as other sterilants, but its delayed action was effective against all the tested weeds except Bermuda grass.

Lewis (1968) compared several herbicides for soil sterilization and general weed control in Florida soils. Monuron was applied to soil containing annual grasses, such as Bahia, spurge, pokeweed, Bermuda, vasey grass, nut sedge, crabgrass, and smut grass. The results of the tests, using a weed control rating of 0 to 10 (0 = no control and 10 = complete control), showed that monuron, 2 months later, applied at 40 lb/acre had a rating of 8, declining to 7, 11 months later.

Dunn (1967) evaluated several sterilants for control of weeds and brush in riprap along levees in Louisiana. Weeds included square stem, coffee bean, pack, goat, yankee, and ragweed; brush included false willow trees and tallow; and grasses present were Bermuda and vasey. Monuron was applied at rates of 20, 40 and 60 lb/acre. At 40 and 60 lb/acre, false willow was completely controlled, and 80% control of Bermuda and vasey grass occurred. At 20 lb/acre the control was much less and the grasses reappeared.

Upchurch et al. (1969) also compared the soil sterilization properties of several herbicides in North Carolina soils. Dominant grasses were tall fescue, Bermuda grass, horse nettle, broomsedge, Johnson grass, and trumpet creeper. Monuron at 40 lb/acre, applied in early spring, gave good vegetation control for 1 yr after which retreatment was required to maintain reasonable control.

Weldon and Timmons (1959) evaluated several herbicides for control of miscellaneous weeds in a farm irrigation ditch in Wyoming. Within 2 months, monuron at rates of 10, 20, and 40 lb/acre gave 98 to 99% control. However, control after 19 months dropped to zero. When a second application at 10 lb/acre was made 1 yr after an initial 10 lb/acre rate, 40% control was evidenced after 19 months.

The possibility of converting southern desertland into more productive grassland prompted Schmutz (1967) to evaluate several herbicides for control of the creosotebush, whitethorn, and tarbush in the Chihuahuan Desert near Tombstone, Arizona. Monuron was applied at rates of 2, 4, and 8 lb/acre. At the 2-lb/acre rate, very little effect was observed on the grasses. At the 8-lb rate, almost complete death of the grasses was observed; near sterilization of the soil was observed for 3 yr.

Long-term studies of the effect of massive application of monuron to the soil were conducted by Isenee et al. (1973). Rates of monuron varying from 56 to 224 lb/acre were applied to soil near Beltsville, Maryland, in 1954. This resulted in 99 to 100% reduction of broadleaf weeds after the first yr. However, even at the heaviest dose, 47% of the area was covered with vegetation at the end of the second yr. This increased to 80% at the end of the third yr and 100% at the end of 15 yr.

Effect on Specific Grasses - Monuron has been shown to be effective against nut grass. Loustalot et al. (1954) found that 80 to 90% reduction in the number of tubers was achieved in plots that were plowed under and treated with 80 lb/acre of monuron. The rate of control depended upon the depth of the tubers in the soil since monuron did not move more than 2 in below the soil.

Szabo and Gould (1959) evaluated various rates of monuron for control of field bindweeds. The degree of control after 2-1/2 months was 99.45% with 40 lb/acre of monuron and 97.45% with 90 lb/acre.

Clubmoss is a serious competitor of grasses on Western rangeland. Stroud and Baker (1966) evaluated several herbicides for control of clubmoss in the late fall of 1964 and early spring of 1965. Monuron applied at a rate of 1.0 lb/acre in the fall of 1964 provided 81% control. Clubmoss control in the spring of 1965 was only 31%, and the yield of total vegetation compared to an untreated check plot was 122%. When 2 lb/acre of monuron were applied in 1965, control of clubmoss was 98%; the yield of total vegetation was 109% of the total vegetation on the untreated check plot.

Effect on Woody Plants - Hoffman (1964) evaluated several herbicides for control of woody species in Texas. He found that 4 g of active monuron were required for effective control of 4-in mesquite. A mixture of 10 lb/100 gal of water was applied in a narrow band around the base of the tree to achieve this control.

Scifres et al. (1974) found that monuron did not cause significant foliar damage to redberry juniper at rates up to 2 g/ft canopy diameter during tests conducted in north Texas.

Economic Benefits of Weed and Grass Control

Hand labor and mechanical control with various devices, such as mowers, discs and bulldozers were considered as alternative costing methods to chemical crop control.

McHenry and Parsons (1967) compared various methods of controlling canal bank weeds in California. In a survey of irrigation districts, they found that chemical costs for soil-applied herbicides averaged \$46.78/acre, mechanical weed control averaged \$12.10/acre, burning of weeds averaged \$13.85/acre, and hand weeding averaged \$164.91/acre.

The results of these various field evaluations show that the economic benefits of chemical control over other methods varied from a loss of $34.68/acre when compared to mechanical weed control on California canal banks to a gain of $118.13/acre when compared to hand weeding along the same area.

The results of these tests are summarized in Table 17:

Table 17: ECONOMIC BENEFITS OF CHEMICAL AND ALTERNATIVE CONTROL

Alternative Control		Chemical Control	Economic Benefit	
Type	Cost ($/acre)	Cost ($/acre)	($/acre)	Source
Mechanical	12.10	46.78	(34.68)[b/]	a/
Burning	13.85	46.78	(32.93)	
Hand weeding	164.91	46.78	118.18	

---

a/ McHenry and Parsons (1967).

b/ Data in parentheses represent negative values.

References

Aldred, J. R., "Soil Sterilants on Silt Loams of the Tennessee Valley Region," South. Weed Sci. Soc. Proceedings, 21:265-272 (1968).

Bost, W. M., Director, Cooperative Extension Service, Mississippi State, Mississippi, personal letter to D. F. Hahlen (1974).

Dunn, C. R., "Riprap Test Work on Lake Pontchartrain Levees," South. Weed Sci. Soc. Proc., 20:207-211 (1967).

Headley, J. C., and J. N. Lewis, The Pesticide Problem: An Economic Approach to Public Policy, Resources for the Future, Inc., Washington, D.C. (1967).

Hoffman, G. O., "Brush Control with Substituted Urea Herbicides," South. Weed Conf. Proc., 17:391-393 (1964).

Isenee, A. R., W. C. Shaw, W. A. Gentner, C. R. Swanson, B. C. Turner, and E. A. Woolson, "Revegetation Following Massive Application of Selected Herbicides," Weed Sci., 21(5):409-412 (1973).

Lewis, W. F., "Tests of Soil Sterilants in West Florida on Sand Soil," South. Weed Sci. Soc. Proc., pp. 273-274 (1968).

Loustalot, A. S., H. J. Cruzado, and J. S. Muzik, "Effect of CMU on Nutgrass (Cyperus rotundus L.)," Weeds, 2:196-201 (1954).

McHenry, W. B., and P. S. Parsons, "Cost of Controlling Canal Bank Weeds by Water Agencies," California Weed Conf. Proc., 19:38-41 (1967).

McKesson Chemical, Kansas City, Missouri, personal communication to D. F. Hahlen (1974).

McRae, G. N., H. F. Arle, and K. C. Hamilton, "A Study of the Effects on Seedling Cotton of Urea Herbicides Applied by Different Methods," Research Progress Report Western Weed Control Conference (1959).

☆ U.S. GOVERNMENT PRINTING OFFICE: 1975— 210-810:67